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Estimating the distributive impacts of climate mitigation policies in the power sector in Ghana

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Introduction

Global efforts have been used to encourage developing countries to implement policies and programs to reduce their carbon footprint to minimize the adverse economic and social impacts of climate change. Almost all African countries (53 out of 54- except for Libya) have instituted a Nationally Determined Contribution (NDC) to reduce the impact of climate change through various mitigation and adaptation strategies. In such efforts, the benefits of mitigating climate change are emphasized, while the potential adverse effects of transition on the economy receive less commensurate attention. Particularly for many continents with heavy reliance on rainfed agriculture, high poverty levels and rising inequality, there is limited evidence and understanding of the growth and distributional effects of pursuing such mitigation and adaptation policies and programs. The impact of NDC policies on the broader macroeconomy and welfare impacts on the vulnerable population in these countries have received less attention. A deeper understanding of the full scope of effects is critical to guide policymakers in designing and considering alternatives that may effectively achieve the dual goal of reducing greenhouse emissions and ensuring sustainable and equitable growth.

Ghana's annual emissions to global emissions increased from 0.01 % in 1950 to 0.04 % in 2016 (Ritchie et al., 2020), and by 2019, the total emissions had increased by 16.3 % (Ghana Green House Emissions Report, 2021).[1] Between 2016 and 2019, emissions increased from 48 million to 59.8 million metric tons of CO2 equivalent (MtCO2e). The most recent national emissions data shows the energy sector as the significant source of primary greenhouse emissions, accounting for 45.7 % of Ghana's emissions, followed by the forestry and other land use sectors, accounting for most of these emissions at 44.6 %. The waste sector recorded reduced emissions from 7.5 % in 2016 to 6.9 %in 2019. Between 1990 and 2019, all sectors recorded increases in emissions except for the industrial processes and produce use (IPPU) sector, which recorded a decline of 11.8 %. Within the energy sector, stationary combustion (e.g., power plants) accounts for about 36.7 % of the emissions, with transport emissions increasing by about 45.8 %, above the values recorded in 2016. Between 2016 and 2019, stationary combustion emissions increased by a third (31.5 %), making the energy sector a high priority in Ghana's commitments. The rise in stationary combustion emissions may be due to the expansion of electricity power plants, increased fuel use in the manufacturing industry, and changes in household energy consumption patterns.

The power sector remains a significant contributor to global climate change (Kang et al., 2020), requiring the most attention. The current rate of climate change is a global threat to sustainability (Abbass et al., 2022), and mitigation efforts have drawn significant attention in recent years (Kang et al., 2020).

In line with the mitigation strategies outlined with the NDC, emphasis is placed on decarbonizing oil and gas production, increasing renewable energy penetration by 10 % by 2030, promoting low-carbon electricity generation and facilitating the adoption of clean rural household lighting (MESTI, 2021). These policies and programs are expected to promote energy efficiency at all levels - households, businesses, and industries. This underscores the critical need to address emissions, particularly from the power sector, to mitigate the effects of adverse climate change. Ghana, like many other developing African countries, has demonstrated their commitment to transitioning to a low-carbon economy through its Nationally Determined Contributions (NDCs). The issue of climate change, its mitigation policies, and their distributional impacts on economies, especially those that are less

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[1] https://unfccc.int/sites/default/files/resource/gh_nir5_15052022_final.pdf

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developed, have been explored by many researchers. While some researchers focused on the effects of climate change on economic growth and development (see Asante and Amuakwa-Mensah, 2014; Arndt et al., 2015; Oduro et al. (2020), others focused on the growth effects of climate change mitigation policies and the channels through which the effects are realized (see Bogdanov et al.,2021; Bowen & Fankhauser, 2011; Fankhauser and Jotzo, 2018; Hallegatte et al., 2012).

Similarly, using a Representative Concentration Pathways–Shared Socioeconomic Pathways (RCP-SSP) framework and the Asia-Pacific Integrated Model/computable general equilibrium (AIM/CGE) integrated assessment model, Liu et al. (2020) explored the multi-sectoral consequences of climate change. They documented the macroeconomic costs associated with climate change mitigation and that technological development ameliorated the costs associated with mitigation activities. Beyond the growth effects, some researchers (see Altieri et al.,2016; Caetano & Merven, 2017; Campagnolo & Davide, 2019) explored low-carbon transition policies' employment and welfare implications.

Arndt et al. (2015) generally investigated the potential economic impacts of climate change in Ghana in the long term. Their study employed a computable general equilibrium (CGE) model and social accounting matrix (SAM) to estimate the economywide effects of climate change across 37 sub-sectors, the majority of them being in agriculture (i.e. 14) and industry (i.e. 17). Historical data on climate from 1951 to 2000 and projections for 2046–2050 were used to simulate four (4) climate projections. Their findings indicated that climate change persistently reduces economic welfare. The finding further revealed that the poor and urban households and the Northern Savannah zone are the most affected. The study thus suggested multi-faceted sectoral approaches to mitigate the effects of climate change.

Similarly, Asante and Amuakwa-Mensah (2014) undertook a comprehensive review of climate change in Ghana, examining, among others, the impacts of climate change on various sectors such as agriculture, health and energy, and their implications on poverty and welfare. The study established that climate change led to low crop yields and morbidity incidences, including cholera, measles, and cerebrospinal meningitis. Further, the study concluded that this negative exacerbates the plight of the poor, reducing welfare and perpetuating poverty.

On the climate change mitigating impacts on economic growth, Bowen and Fankhauser (2011), in an Oxfam discussion paper on low-carbon development for Low and Developing Countries(LDCs), explored the rationale of mitigating carbon emissions while ensuring poverty reduction in LDCs. Combining empirical data, case studies and theoretical studies, the authors argued that the fundamental challenges of mitigating climate change, adjustments to the consequences, and the reduction of poverty must be considered together. Also, they posited that the effect of low-carbon transition on economic growth and development was heterogeneous among LDCs and largely dependent on the primary source of carbon emissions, so LDCs needed to follow low-carbon growth paths suitable to their various needs. The high initial cost of low-carbon transition policies coupled with low levels of capital accumulation in LDCs was a significant challenge to economic growth and development. They, therefore, stressed the need for international cooperation between LDCs and high-income economies in combating climate change while considering the development requirements of LDCs, which are especially susceptible to the effects of climate change mitigation policies.

Recent studies by Campagnolo and Cian (2020) and Campagnolo and Davide (2019) have also documented changes in poverty as a result of climate change mitigation activities, as do Fujimori et al. (2023), who report the potential for climate change to increase global poverty headcounts. Similarly, in their Green Growth literature, Hallegatte et al. (2012) explored the distributional impacts of green growth policies, providing an analytical framework for understanding the channels through which these policies impact economic growth. Drawing from empirical findings across countries and analytical frameworks, they argued that the distributional impacts of low-carbon transition policies could be positive or negative. For instance, a policy such as removing subsidies on fossil fuels could lead to positive distributional implications for income since the larger share of subsidies goes to the rich, who consume relatively more energy. At the same time, though people with low incomes may not have cars and access to electricity-dependent appliances, the subsidies on fossil fuels form a large share of their income; thus, removing the subsidy would lead to negative welfare implications for people experiencing poverty. Apart from this subsidy effect analysis, they also observed that low-carbon transition policies, in general, come with economic costs in the form of initial investments or operational costs. These costs, however, persist in the short term, leading to trade-offs between environmental sustainability and economic growth. Meanwhile, in the long run, green growth policies towards environmental sustainability have positive ripple effects on economic growth through job creation and improved efficiency.

Fankhauser and Jotzo (2018) draw similar conclusions to Bowen and Fankhauser (2011) as they sought to investigate the impacts of climate change mitigation on economic growth and development in developing countries, specifically in South Asia and Sub-Saharan Africa. The authors discuss the trajectories of energy and emissions intensity vis-à-vis their economic implications. Their study underscored that reducing carbon emissions, or decarbonization, requires investments in clean, renewable energy sources, which could double the cost of energy production. They observed, however, that the effect on economic growth varies between countries – the rich countries may experience economic (GDP) growth in the short term as they inject new investment capital into decarbonization policies. In contrast, poor countries may have to displace other investments favouring decarbonization, leading to growth reduction. They also indicated that carbon mitigation policies perpetuate poverty among the poor, so governments must choose policy mixes that protect the rich and the poor.

Bowen et al. (2015) further investigated the implication of climate change adaption on economic growth and development using evidence from simulation models and empirical research from a global perspective. While they emphasized a positive relationship between climate change adaptation and economic growth, they indicated that an economy's capacity depended on its institutional quality and financial intermediation. This factor could delay growth in developing economies in the short to medium term. Similarly, Nyasapoh et al. (2023) provide empirical evidence on the effectiveness of clean energy technologies in mitigating climate change and promoting economic growth. Their model shows that increasing the installed capacity of renewables and nuclear energy significantly reduces CO2 emissions despite higher initial investment costs.

Regarding the employment and welfare effects of low-carbon transition policies, Altieri et al. (2016) conducted a study on South Africa, characterized by high unemployment rates, poverty, and an emissions-intensive economy. To explore how the dual goal of low-carbon transition and development could be through a decarbonization pathway, the study employed an energy-system optimization model (TIMES) and an economywide computable general equilibrium model (e-SAGE) to examine the effects of changes in the energy sector, by targeting a 14 GtCO2e cumulative energy sector carbon constraint by 2050. They conclude that low-carbon emission policies have employment and poverty-reduction implications.

Furthermore, Caetano and Merven (2017) explored the employment and household welfare impacts of a robust transition to decarbonize energy sector using a fully linked intertemporal bottom-up optimization energy model for South Africa (SATIM-F) together with a dynamic general equilibrium model (e-SAGE) methodology with data spanning from 2010 to 2050. The study highlighted that a rapid transition to decarbonize the energy sector would have adverse socioeconomic impacts, especially on welfare and employment. Specifically, projected job losses in the unskilled labour sector are making poor households worse off. Using cross-country data, Campagnolo and Davide (2019) potential negative impacts on poverty reduction with limited robust evidence on inequality.

In sum, studies such as Caetano and Merven (2017), Altieri et al. (2016) and Campagnolo and Davide (2019) have reported negative impacts of mitigation policies on economic growth and examined employment and welfare impacts of low-carbon transitions in the South African context. These studies show that the adverse effects of the transition to decarbonization disproportionately affect low-income households as they are projected to experience rising electricity prices and increased job losses (Caetano & Merven, 2017). However, such detailed economywide and micro-level impacts are limited in other contexts in sub-Sahara Africa. Especially in the face of the heavy reliance on fossil fuel as a major energy source in the sub-region, it is imperative to document how the planned policy actions reflected in the NDCs may impact economies in other countries.

This paper contributes to the debate on the impact of the NDC by considering a more country-specific assessment of the impact of climate change mitigation strategies. The current analyses go beyond the cross-country level assessment of the Paris deal by Campagnolo and Davide (2019), which focuses on a combination of developing and developed countries. Given the heterogeneity in the countries in the sub-Sahara region and the variations in their commitment levels as indicated in their respective NDC, a country-level assessment apart from what is documented for South Africa is critical. From a methodological point of view, the current study contributes to the literature beyond the reliance on CGE modelling, which considers national aggregated emission targets. Campagnolo and Davide (2019) focus on each country's NDC. This masks the potentially nuanced effects due to differences in each country based on which sector contributes the largest to county-level emissions. Understanding such sectoral-level impacts is critical for targeted policymaking. In this study, the focus is on mitigation in the power sector rather than on Ghana's NDCs. The study employs a modelling framework which combines a detailed full-sector power optimization model for Ghana with a dynamic recursive CGE model. The power sector model ensures that the power sector pathway identified to meet the desired mitigation requirements meets the engineering and physical requirements of the power sector. The link to the economic model allows the assessment of changes in the power sector in the economy and ensures that. It provides behaviour due to these impacts, which are factored into the demand for power in the country. Outputs from the linked model are also soft-linked to a microsimulation model, thus enabling a detailed assessment of household impacts. The current study also considers different financing modules to allow for a comparison of results an.

The linked model is, therefore, ideal for evaluating country-level macroeconomic and distributive impacts of both moderate and ambitious mitigation strategies outlined in Ghana's different financing sources. Based on this broad objective, we answer the following questions:1) What are Ghana's mitigation strategies' short-term and long-term impacts on growth, employment, poverty, and inequality in its updated NDC? 2) How do these impacts vary under moderate and ambitious scenarios? 3) How do different financing options influence these impacts?

The following section discusses the study and policy context, and the framework adopted to evaluate the impacts of climate action. Under section 3, we introduce the reference case and discuss the two mitigation strategies we consider - moderate and ambitious. Section 4 discusses the findings by showing the implications for the macroeconomy, employment, and distributive effects. The section further shows how the impacts change when foreign financing is considered. Section 5 summarizes the findings and discusses the study's limitations and future work.

Materials and methods

Study context

Structure of the Ghanaian economy

Like many other sub-Saharan African countries, Ghana is vulnerable to climate change (Arndt et al., 2015), mainly due to the structure of its economy. Although recent data from the World Bank Indicators indicate that the agricultural sector contributes only about 18.9 % of GDP, the sector employs over a third (about 39 %) of the population and most of these are small-holder farmers who rely on traditional technologies and are therefore characterized by low yields (Arndt et al., 2015).

Given its location, Ghana is vulnerable to climate change, especially in the agricultural sector, where weather inputs play a major role in its agricultural productivity. Future projections by Asante and Amuakwa-Mensah (2014) estimate that climate change and its impacts on the agricultural sector in Ghana are significant, with the fisheries sub-sector being severely affected by rising sea levels. In the crop sub-sector, the changing climatic conditions in the cocoa growing areas are projected to become unsuitable, thus reducing the productivity of the cash crop by 2050. Again, the production of other crops, such as rice and tubers (especially cassava), will be adversely affected by the projected climate change and variability, as shown by Nutsukpo et al. (2012) and Amponsah et al. (2015), who argue declines in crops yields from 4 to 20 % for rainfed crops like maize, rice, and groundnut across the country by 2050.

The industrial sector is confronted with its vulnerabilities in the changing climate. Climate change primarily affects the industrial sector through the energy sector, infrastructure, and people's safety risks. Climate change is projected to negatively impact the infrastructure systems that support industries, including the energy sector. Unsafe weather conditions can affect industries such as the oil and gas industry. Again, rising sea levels could adversely impact power plants in coastal zones and risk oil and gas transportation through coastal pipelines.

Further, the electricity grid and the generation of electricity in some critical locations may be poorly affected by high global temperatures, as noted by Kwakwa (2015), Kabo-Bah et al. (2016) and Boadi and Owusu (2019) in Ghana. This effect on electricity production, in turn, could affect the industry sector (Abokyi et al., 2019). Other industries that rely on the national grid as their primary electricity source also suffer indirectly from the adverse impact of climate change. Deteriorating road infrastructure has been associated with climate change (Twerefou et al., 2015).

These adverse effects of climate change ultimately exacerbate existing levels of poverty and inequality, thus described as 'the multiplier'. Wodon et al. (2014), Gentle et al. (2014) and Hill and Mejía-Mantilla (2014) have consistently shown this across different contexts where poor households suffer the most from climate change, which manifests in more significant losses in crops, livestock and income. Heterogeneous impacts are observed in vulnerable populations, particularly women and children from developing contexts, disproportionately experiencing larger adverse impacts. In Ghana, Nkegbe and Kuunibe (2014) and Adzawla and Kane (2019) find similar evidence of the threat multiplier, where evidence points to the impact of climate variability on welfare outcomes.

Poverty and inequality trends in Ghana

With steady and impressive economic growth in the past decade, Ghana attained lower-middle-income status in 2010, with GDP growth rates peaking at 14 % in 2011 and oil revenue contributing significantly to the economy's growth. Over this period, Ghana recorded significant declines in poverty, with the poverty rate reducing by half from 42.47 % to 25.69 % by 2012 to achieve the Millennium Development Goals. After 2015, a combination of factors such as macroeconomic policies, institutional rigidities, and shocks (International Monetary Fund, 2016) resulted in significant declines in economic growth rates to about 2.1 in

2015 before rising again in 2017 and then later to 0.5 % in 2020 due to the impacts of the Covid-19 pandemic and other macroeconomic policies. According to World Bank Data, the post-COVID-19 growth rate bounced back to about 5.1 % in 2021 and declined significantly to 3.8 and 2.9 %, respectively, in 2022 and 2023.[2] The decline in 2023 was mainly driven by the industrial sector's decline of about 1.2 % from subsectors, including oil, electricity, gold, and manufacturing. Given the current macroeconomic challenges, growth is expected to remain weak throughout 2024 at a projected rate of 2.9 %. However, the growth trajectory will likely return to its long-run potential of 5 % in 2025 and 2026 as the current economic crises stabilize in the subsequent years because of the ongoing fiscal consolidation measures.

Consequent to the current economic crises, poverty is projected to be at its highest level in over a decade, according to the World Bank Macro-Poverty Outlook report in 2024. Similarly, inequality, which has been increasing steadily for the past two decades, is projected to continue to rise, reaching 0.44 by the end of 2024This indicates that economic growth has not been inclusive. Between 1992 and 2017, inequality, measured by the Gini coefficient, has increased steadily from 0.37 to 0.43 respectively. Particularly between 1999 and 2006, the country recorded its highest increase in inequality, with the rate increasing from 0.39 to 0.42. Inequality is highest in regions with the highest prevalence of poverty. The data also suggest that poverty and inequality are primarily rural phenomena and are highest in the three northern regions (Northern, Upper East and Upper West). These regions also coincide with the ecological zones, which are more vulnerable to climate change.

Framework for assessing climate action impacts

The distributional impacts of climate actions in Ghana are assessed using a linked power sector-economic model with outputs linked to an accounting-based microsimulation module for poverty and inequality estimations (see Fig. 1). The linked model, referred to as GHATIM-GE, is a modelling framework in which two individual models, namely the Ghana TIMES (SATIM) model and an energy-extended version of the Ghana General Equilibrium model, are hard-linked through the iterative exchange of information. This approach is well placed for climate action analyses and ensures comprehensive consideration of the physical properties of the power system, along with appropriate costs and constraints. Moreover, it estimates the economic impact of power system changes and incorporates power demand feedback into capacity planning.

The power sector model

The TIMES model of the power sector in Ghana is a technology-rich, partial equilibrium optimization model. Within the model, power plants are represented in terms of the fuels they use, their capital and operating costs, other technology characteristics such as the efficiency and availability of the power plants and the GHG emissions associated with fuel use by the plants. Demand for electricity in the model is disaggregated into household, industry, and other demands and represented in terms of a daily load profile for each of these sectors. The profile allows the changes in demand for a day or season to be captured. These changes are represented in 10 daily time slices to depict a “typic” l” day” and over three seasons to capture seasonal variations in demand. The model is calibrated to a base year 2020 for the demand sectors. Demand for electricity in 2020 is 16,531GWh. The residential sector is the largest consumer, using 7765 GWh, followed by industry, which used 5499 GWh.

All the power plants operating in 2021 and those under development are represented individually in the model. The model, therefore, includes 4.8 GW of dependable capacity in 2021, of which 3.31GW are thermal plants, 1.4GW are hydro, and 84 MW are renewables. A further 225 MW of wind at the Ayitepa wind farm is committed to come online in 2023.

Where the availability of power plants, such as wind, solar, and run-of-river hydro plants, is variable and uncertain, the daily and seasonal availability of the plants follows an anticipated daily and seasonal profile. The availability of runoff river hydro plants follows the seasonal variability of river flow. Where hydro plants follow a dam, seasonal and interannual storage is possible up to the individual dam capacities. Similarly, the availability of solar and wind plants is location-specific and follows the variation in renewable resources over the day and seasons. Solar plants can, therefore, only generate electricity during the day. The annual capacity of solar plants ranges from 0.17GW to 0.19GW. Annual wind capacity factors in the model range from 0.25GW to 0.39GW, depending on the location.

Several power purchase agreements are concluded as take-or-pay contracts. These contracts are predominantly associated with thermal power plants. Where it was known that a plant was under a take-or-pay contract, these plants are modelled to incur a minimum operating cost regardless of whether electricity is generated. To allow the model to choose whether or not to run the plants and at the same time capture the total cost of these contracts, the cost of running the plant up to the level of supply falling under the take-or-pay contract is modelled as a fixed operating cost; if the plant is generating electricity above the level of the take-or-pay contracts, fuel costs and variable operation and maintenance costs reflect the actual cost of running the plant.

Battery storage is included as an option. Batteries can store electricity generated by plants and then discharge the energy as needed. Unlike dam storage, which can store water in one season for use in another, batteries can only store energy over a day. However, storing energy in batteries is associated with a slight loss of power.

In the system optimization, the cost of fuels, capital and operating and maintenance costs, expected plant life, efficiency and availability factors of individual plant options all inform the optimized models for new capacity additions. Tables A1 to A3 in the Appendix summarise the cost and performance characteristics of the technologies included in the model and fuel costs. Any constraints imposed, such as the speed at which new capacity of a particular generation technology can be added, the total capacity that can or must be added to the solution for different generation types, environmental constraints, etc., will be reflected in the results. All plants have an assumed lead time, which varies according to the technology. New capacity investments are possible for wind and solar plants, hydro plants, generic oil, gas and coal plants. The capital costs and maintenance costs of new wind and solar plants decrease over time to reflect technology learning, making these plants more attractive from a cost perspective in future years. In the Ghana model, constraints are imposed on the amount of new capacity additions that can occur for a particular technology. For example, solar capacity additions are capped at 0.5GW per year throughout the model period, whereas additional wind capacity is capped at 0.5GW in 2023, increasing to 5GW by 2050.

Fuel use generates GHG emissions. These emissions can be constrained to a maximum at a specific time or constrained at a cumulative amount between specific years.

The combination of plants, fuels, emissions, demand sector disaggregation and temporal representation provides a least-cost technology mix that can meet the total demand, including transmission losses at the temporal resolution specified over the modelling period.

Computable general equilibrium (CGE) model for Ghana

The CGE model for Ghana is a dynamic recursive, economywide computable general equilibrium (CGE) model built on the framework from Diao and Thurlow (2012). CGE models are useful simulation tools for distributional policy analysis as they capture the functioning of a market economy in which the interactions of economic agents are mediated via prices and markets, with macroeconomic and resource constraints respected. The model includes detailed information on sector

[2] World Bank, Poverty & Equity and Macroeconomics, Trade & Investment Global Practices

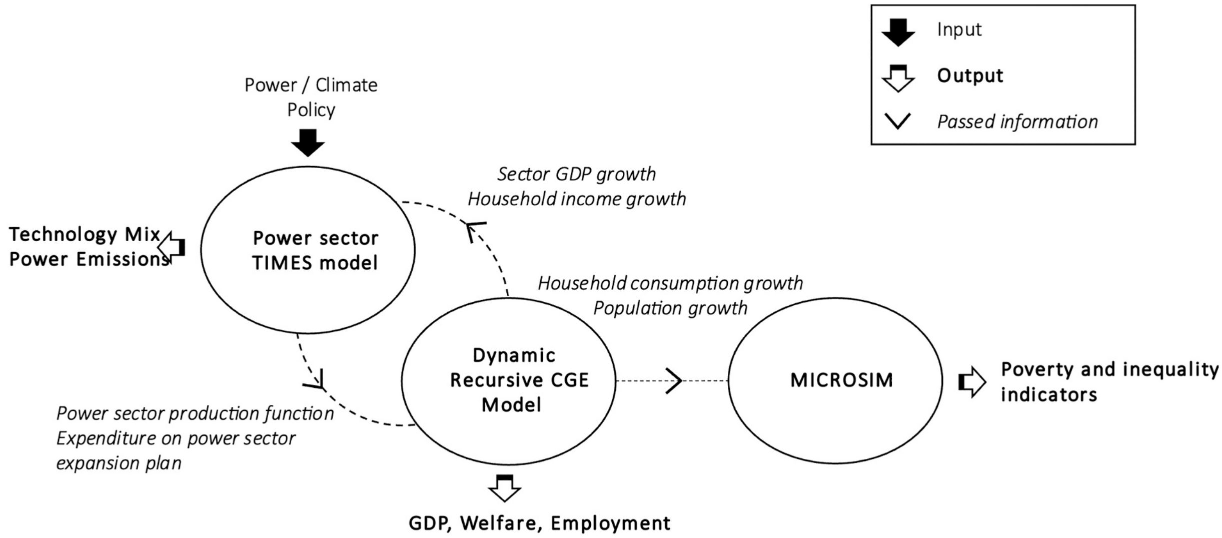

Fig. 1. illustrative diagram of the modelling framework.
Source: Authors' Illustration.

production and intermediate use, including factor use. Detailed information on household income and expenditure is also included, along with linkages to the production sector represented by returns to households for factors of production provided to the market and spending of households on goods and services produced and supplied to the market. The general equilibrium framework of the model adjusts prices so that markets are clear. These price changes inform the level of household consumption expenditure. The Ghana CGE model includes representative household quintiles by rural farm, rural non-farm, and urban region.

The Ghana CGE uses an enhanced version of the 2015 SAM for Ghana, developed by the International Food Policy Research Institute (IFPRI), to inform the economy's underlying structure in the base year. The SAM is enhanced by matching the power generation and consumption data to the energy statistics for Ghana to ensure that the models are consistent. A key feature of the Ghana CGE model used in GHATIM-GE is household consumption behaviour over time. Most CGE models assume a Linear Expenditure System for household expenditure. The Ghana CGE model uses a Cobb-Douglas approach, changing consumption shares over time in line with changes in household incomes to account for changes in living standards. For example, if incomes in the poorest 20 % of households increase to the level of the poorest 40 %. The consumption shares are adjusted to reflect the profile of households in the poorest 40 %. Such an evolution in household consumption is better suited for long-term analysis as it better captures the welfare-enhancing feature of modern economic development" (Cha", 2018). Such an approach is also important for understanding household energy needs as fuel type demands evolve with lifestyle changes. See Merven et al. (2020) for a detailed description of this approach.

While the Ghana CGE model allows for some household distributional analysis, including disaggregated household sectors, the household groups in the model are still representative households (i.e., households are an aggregate group of households and not an average household). A top-down micro-accounting approach following Pauw et al. (2011) is taken to extend the distributional analysis of climate actions on households. Under this approach, economic outcomes from the GHATIM-GE modelling framework are soft-linked to a microsimulation module to calculate expenditure-based inequality and poverty estimates. The Ghana Living Standards Survey (GLSS) 6, used to calibrate the household development of the 2015 SAM, informs the base year calculations. Each household in the survey is linked to the corresponding household group in the Ghana CGE model through growth in household consumption by commodity group and population, resulting in a different per capita level of expenditure per household across time and scenario. This updated information is then used to recalculate inequality and poverty indicators. This approach allows for a refined interpretation of the effects of poverty and inequality, although within-group income distributions remain constant (Pauw and Thurlow, 2011). The methodology cannot account for the dynamics related to persistent poverty and poverty traps. While no behavioural changes are directly modelled in the microsimulation, behavioural changes from the Ghana CGE model are passed through relative differences in consumption expenditure growth across commodity groups. Domestic poverty lines are used in the modelling framework. Specifically, the 2013 food and upper poverty lines of GHC 792 and GHC 1314, as reported by the GSS (2014), are included. A lower poverty line, the average of the food and the upper are also added to the analysis. Because we are assessing real changes in household consumption, the poverty lines remain unchanged in the microsimulation module, although they are increased to reflect the values in 2015 prices.

Mitigation scenarios

Reference case

The Reference scenario is the business-as-usual scenario for the Ghanaian economy under which no mitigation action is taken. The reference case is the counterfactual scenario to which mitigation scenarios are compared to assess their economic impact. In this scenario, we assume that the economy grows at an average annual rate of 5.8 % per annum between 2015 and 2050. The growth rate is based on actual historical growth and projections. Fig. 2 presents the economic projection.

Exogenous assumptions informing growth are kept in line with historical trends, and sector total factor productivity is adjusted to reach the targeted growth path. As the analysis takes place over the longer term, we assume an upward-sloping labour supply curve. Capital is updated in a dynamic, recursive manner, and as such, it depends on the level of investment made in the previous period. Investment is assumed to be a fixed share of absorption, which 2015 was roughly 26 %. The government balance can adjust to finance shortfalls in expenditures or save surplus funds. In line with the stylized facts for Ghana, the exchange rate is assumed to be flexible. The underlying assumptions included in the reference case are consistent across scenarios to ensure

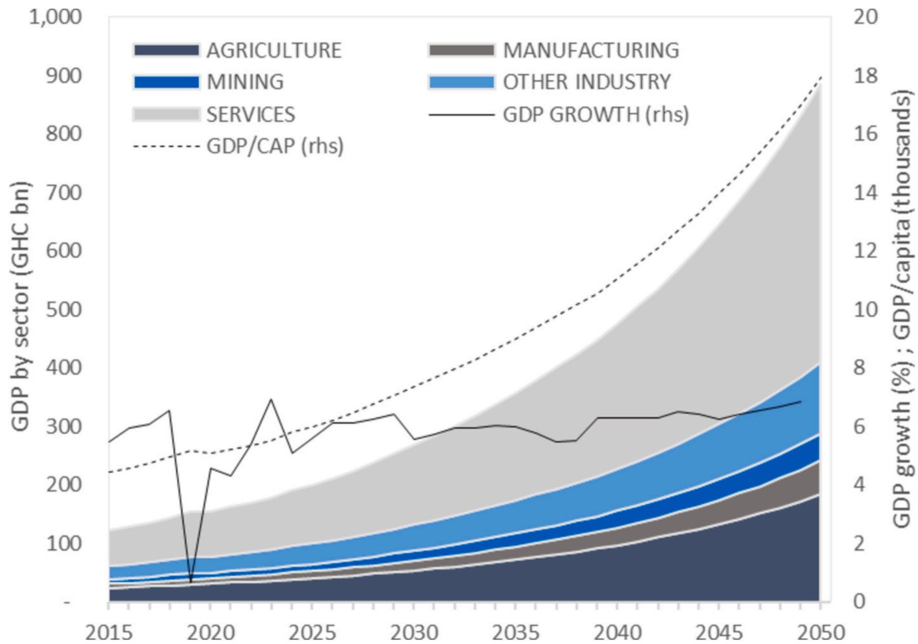

Fig. 2. Reference case economic projections.
Source: GHATIM-GE

that the differences in outcomes result from the climate mitigation actions taken.

Under the Reference case, GDP per capita increased from GHC 4445 in 2015 to GHC 17,932 in 2050 (real 2015 prices). The increase in per capita GDP is driven by the faster growth in GDP relative to population growth. Annual population projections are taken from the U.N. A distinction is made between rural and urban population growth, with rural areas expected to grow at a slower pace of 0.2 % per annum relative to urban areas, which grow at 2.7 %. Rural population growth starts at 0.5 % in 2023 and reaches −0.3 % by 2050. Urban population growth starts at 3.1 % and falls to 2 % by 2050. As illustrated in Fig. 2, all sectors continue to grow in the reference case, although the shares of mining and other industries in the overall GDP decrease.

Manufacturing and services have become a larger part of the economy, and agriculture remains relatively the same. Employment increases as the economy expands, although employment intensity increases due to the more prominent roles of manufacturing and services, the largest employers per output unit following agriculture. In terms of types of employment, more jobs are created for low-skilled workers, with slightly more than half of all new jobs being created for urban workers. Poverty (using the 2013 GSS upper poverty line[3]) decreases over the period from an estimated headcount rate of 23 % in 2015 to 3.1 % in 2040 and 0.7 % in 2050, with the level of people living below the poverty line decreasing to 1.4 million in 2040 and 0.4 million in 2050 from an estimated 6.7 million in 2015. This may be considered ambitious, but as highlighted before, the microsimulation module does not account for the persistence of poverty. Inequality also decreases with the Gini decreasing from an estimated 0.45 in 2015 to 0.44 in 2050.

Moderate and ambitious scenarios

We consider two mitigation scenarios, i.e., Moderate mitigation in line with the Updated NDCs in which emission levels in the power sector are constrained to those of 2015 from 2035 onward, and an Ambitious mitigation scenario under which power sector emissions are reduced to half of those produced in 2015 from 2035 onward. All assumptions are held the same as in the Reference case.

Fig. 3 presents the annual power sector emissions under the Reference case, Moderate mitigation, and Ambitious mitigation scenarios. In the reference case, emissions initially rose due to the continued use of oil. As oil-based power generation is replaced by gas with some solar photovoltaic (P.V.) and wind, emissions stabilize between 2026 and 2035. Higher economic growth post-2035 leads to increased power supply, largely met by increased gas use. By 2050, power sector emissions will be near zero in the Ambitious scenario and 88 % lower than in the reference case. Under the Moderate scenario, emissions are 76 % lower than in the reference case in 2050. The changes in the energy system under each scenario are discussed in later sections.

In the scenarios above, mitigation in the power sector is funded through existing investment resources in the economy. However, many countries depend on foreign assistance to achieve their mitigation goals. Ghana's NDC reflects the potential mitigation of 64MtCO2e by 2030 (relative to a baseline cumulative 2020–2030 emissions). However, only about a third of this commitment is unconditional on international or private investment (MESTI 2021). We, therefore, consider two additional scenarios in our analysis – Moderate + conditional funding (C.F.) and Ambitious+ conditional funding (C.F.) - these scenarios are the same as the Moderate and Ambitious scenarios discussed above, except that all renewable energy power sector projects are funded from foreign funding sources. These scenarios provide a lower bound to the cost of mitigation compared to the previous two scenarios, which indicate a potential upper bound.

Results

Power system changes

Fig. 4 shows the electricity produced by different plant types in each scenario—production of electricity increases to meet the demand for electricity in the three scenarios. Throughout the period, the electricity demand is lower in the NDC scenarios, reflecting the reduction in electricity demand associated with a lower GDP growth. Fig. 4 also shows the production of electricity by plant type. The most striking difference

[3] The 2013 upper poverty line of GHC 1314 per annum is adjusted to match the model with 2015 base data. As poverty is calculated using real consumption expenditure the poverty is not further adjusted over the period.

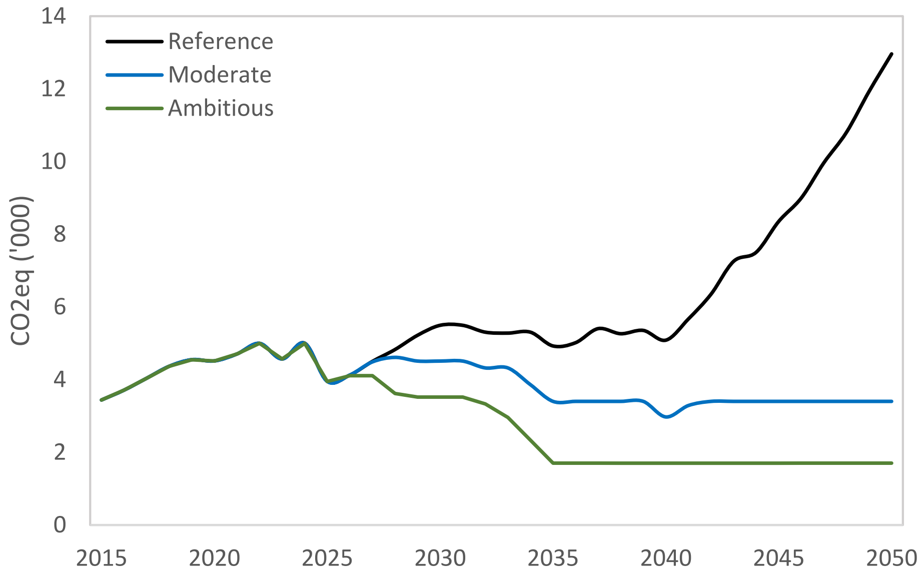

Fig. 3. Annual power sector emissions by scenarios, 2015–2050.
Source: GHATIMGE

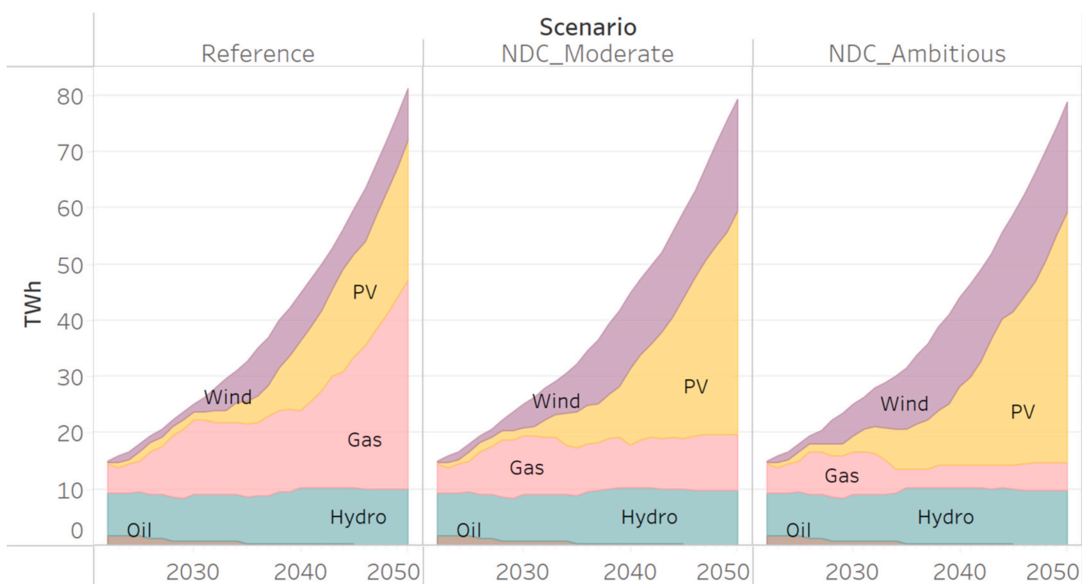

Fig. 4. Electricity production by plant type (TWh).
Source: GHATIM-GE

between the scenarios is the shift from gas generation in the reference case to wind and solar P.V. generation in the NDC scenarios. In the NDC scenarios, the use of gas decreases in response to the emissions constraints imposed in the model. There is an increase in production from P. V. and wind plants and, in particular, a shift towards a greater share of generation from P.V. with a tightening of the emissions constraint. Due to the availability constraints imposed on these intermittent renewables, they can only supply electricity intermittently. To reflect the intermittency of generation from these plants, the supply of electricity from these plants needs to be matched with some investment in battery storage capacity or alternative supply technologies that can generate electricity on demand as required. In the NDC scenarios, to supply electricity when renewable energy (RE) supply is constrained and emissions reductions limit investment in gas, the model invests in large amounts of battery storage by the period's end (Fig. 10). The demand in the NDC scenarios includes the additional electricity needed to cover losses as the battery storage technologies are charged and discharged.

New capacity investments in all scenarios reflect the least cost option for supplying electricity demand. New capacity investments in the NDC scenarios are mainly in solar power, wind, and batteries, replacing the investment in gas in the reference scenario. Tightening the emissions constraint raises investment in these technologies, which can supply the electricity needed at a lower cost than additional hydro capacity. Liquid fuel plants are phased out over the period in all scenarios. Although the demand is similar in the NDC scenarios, the additional capacity needed to replace gas is large. This is primarily due to the assumptions around the availability of solar and wind plants compared to the gas plants in the reference scenario and the battery storage capacity needed (see Fig. 5).

The cumulative investment needed (billions of U.S. dollars) to acquire the additional capacity is shown in Fig. 6. Although electricity generated is lower in the NDC scenarios, the investment needs of the

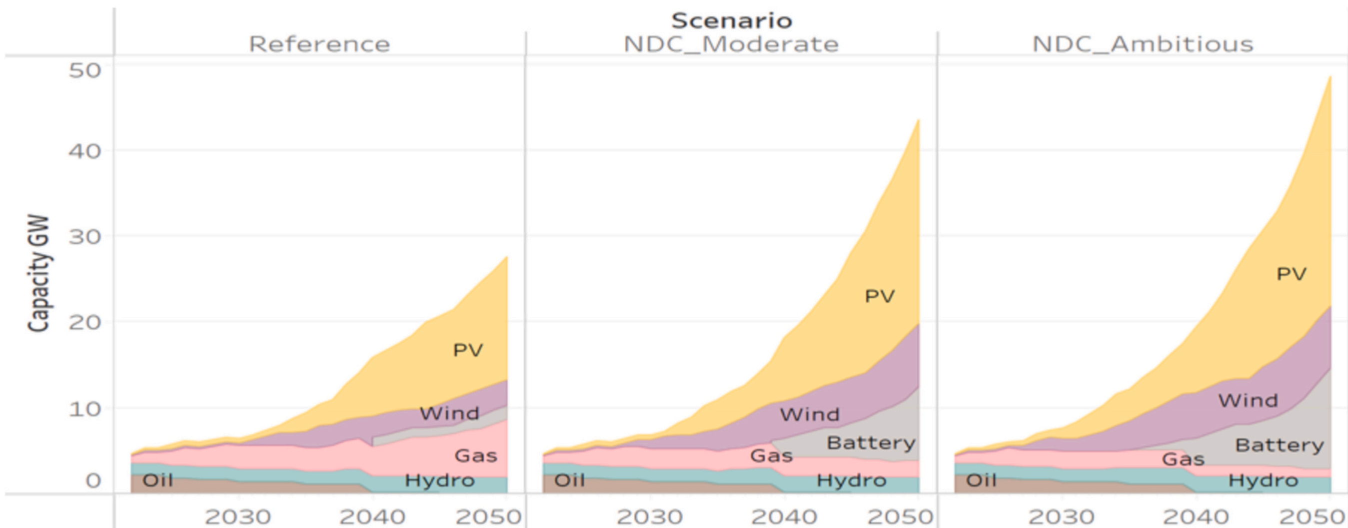

Fig. 5. Electricity capacity by plant type (G.W.)
Source: GHATIM-GE

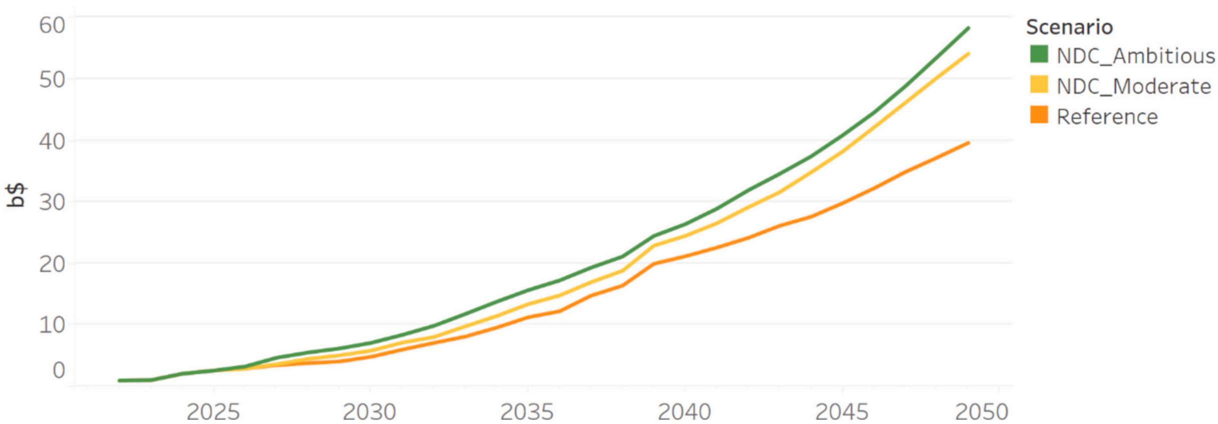

Fig. 6. Cumulative investment in power sector.
Source: GHATIM-GE

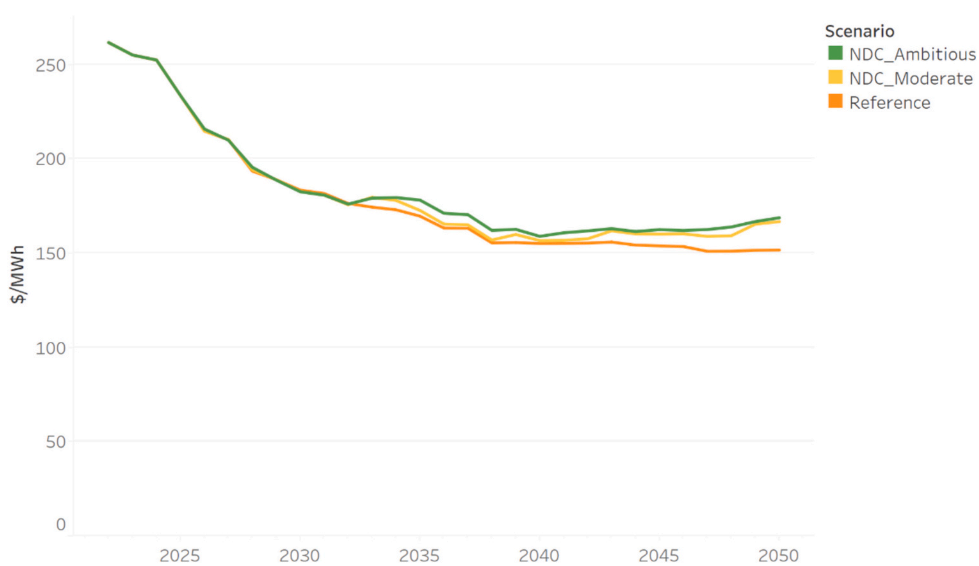

Fig. 7. Price ($/MWh).
Source: GHATIM-GE

power sector are far higher. However, doubling the level of mitigation ambition does not increase investment needs proportionally.

Fig. 7 shows the impact of the investment and production decisions on the electricity price ($/MWh). The cost of producing a unit of electricity drops initially as capacity is more fully utilized and take-or-pay contracts are replaced with lower-cost alternatives. It is assumed in all scenarios that take-or-pay contracts are not renewed but that these plants can continue to run until the end of their plant life. The impact of the additional investment needed in the NDC scenarios can be seen in the higher electricity prices in these scenarios, increasing towards the end of the period. However, it is worth noting that even in the most ambitious scenario, the price remains well below the price in 2020, indicating the high cost of supplying electricity with the current take-or-pay contracts.

Fig. 8 shows the hourly dispatch of electricity from each plant type for two years, namely 2030 and 2050, in the reference scenario compared to the Ambitious NDC scenario. The demand profile is also shown by the red line in the figures, and S1, S2 and S3 refer to seasons 1 to 3, respectively, and D1 indicates the day type. The figure reflects the restriction in seasonal and daily availability of P.V. (donated EPV in the figure), wind, and hydro plants. For example, it shows that the generation of electricity using P.V. is restricted to daylight hours and is lower in winter. In the reference scenario, there is very little battery use, which reflects both the demand for electricity and the subsequent dispatch of electricity for the day.

Economywide impacts

Relative to the Reference scenario, real GDP is lower in the Moderate and Ambitious scenarios. The increased power sector investment needed primarily drives the decrease in real GDP. As mentioned in Section 3, power sector investment is higher in the Moderate and Ambitious scenarios because more renewable capacity is needed relative to gas, and the cost of this capacity is higher in the case of Ghana. In our base scenarios, we assume power sector investment is funded locally. This implies that investment is diverted from other sectors towards the electricity sector, with a smaller financing pool available. The cost of capital for other sectors thus increases, resulting in a decline in investment, which slows production relative to Reference, leading to lower real sector GDP.

By 2050, total real GDP will be 3.3 % and 4.4 % lower in the Moderate and Ambitious scenarios, respectively. This is equivalent to a 0.1 and 0.2 percentage point decrease in the average annual growth rate between 2025 and 2050 and a delay in reaching 2050 Reference GDP levels of less than one year. Relative to the Reference, declines in GDP become more pronounced only after 2040 in the Moderate scenario (less than 1 % before) and after 2030 in the Ambitious scenario. Economic costs are higher in the Ambitious scenario as the higher mitigation ambition requires earlier and larger renewable capacity build (see Table 1).

While lower sector activity is seen across almost all sectors, the impact of mitigation differs. The magnitude of the impact is dependent on the direct exposure to changes in electricity demand, the capital intensity of the sector, the intensity of electricity use, the ability to shift to supplying foreign markets, the elasticity of demand locally, and the strength of linkages with the rest of the economy. Under mitigation, the largest relative decreases in GDP are experienced in Mining and Manufacturing. These decreases are driven by reduced demand for crude oil and petroleum (included in Other manufacturing) from the electricity sector as it switches away from oil-based power. Crude oil and

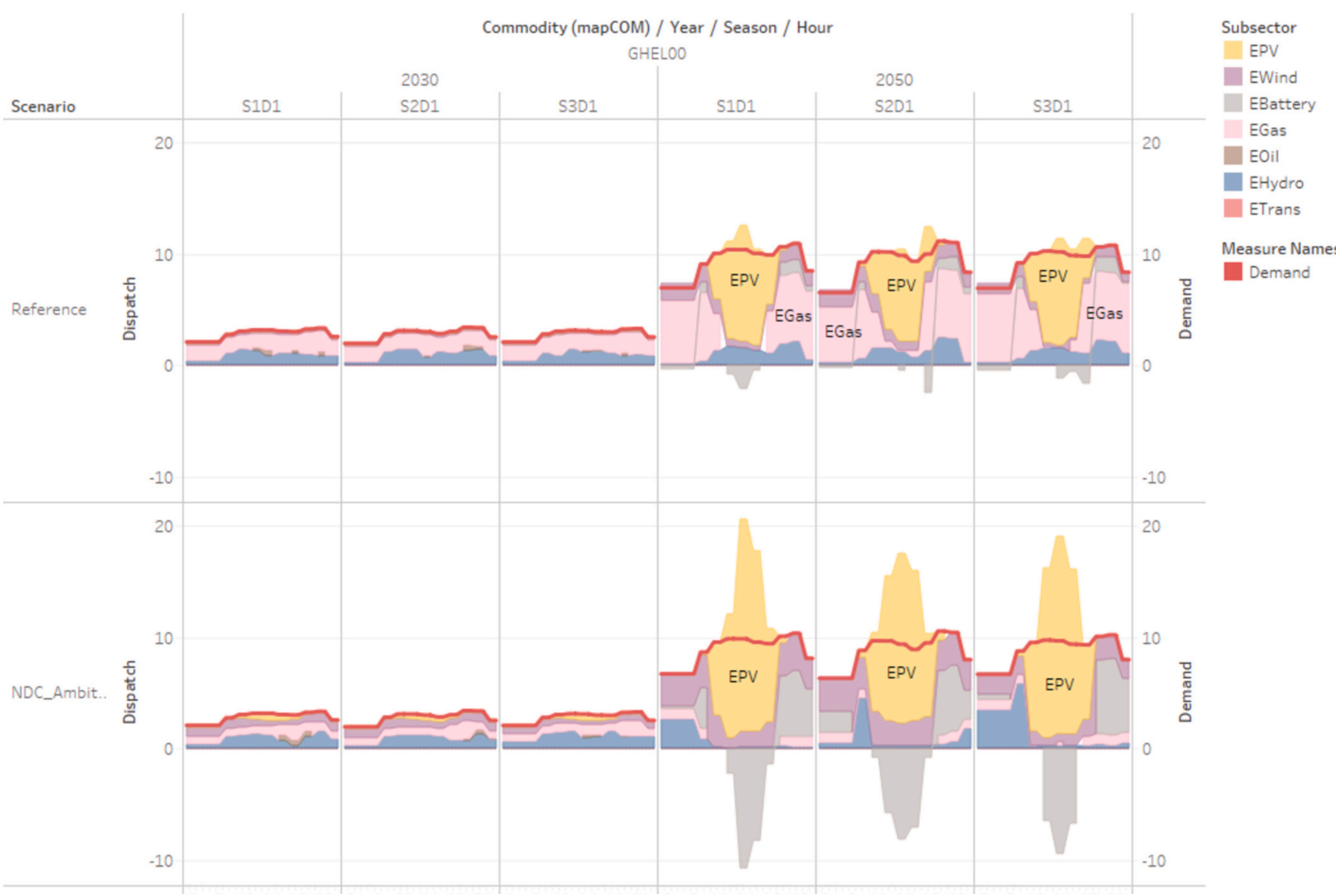

Fig. 8. Hourly Dispatch in 2030 and 2050 for Reference and NDC Ambitious Scenarios.

Table 1
Percentage change in sector GDP and employment relative to Reference by 2050.

	Real GDP (%)		Employment ('000 s)'	
	NDC Moderate	NDC Ambitious	NDC Moderate	NDC Ambitious
Total GDP	−3.3	−4.4	−247	−340
Agriculture	−1.9	−2.4	15	22
Crops	−1.0	−1.3	11	18
Mining	−7.3	−9.8	−28	−40
Manufacturing	−5.6	−7.3	−142	−177
Food	−4.5	−5.4	−107	−125
Other	−6.0	−8.1	−35	−53
Other industry	−2.4	−3.4	38	47
Services	−2.9	−3.9	−130	−193

Source: GHATIM-GE.

petroleum are produced mainly domestically. Gas demand also decreases relative to Reference, although this primarily affects imports. Capital-intensive sectors such as transport, machinery, and chemicals (included in other manufacturing) experience larger relative declines in GDP than less intensive sectors due to the increase in capital costs.

Similarly, GDP decreases are larger for electricity-intensive users such as metals (included in Other manufacturing). The smallest decline in activity (relative to the Reference case) is in the agriculture sector, specifically crop production. Demand for agricultural commodities, particularly those for domestic consumption, is relatively more robust than demand for other sectors. Crop production is also supported by increased production of cocoa, a key agriculture export commodity, as the relative cost of production decreases domestically due to lower labour costs as other sectors reduce their labour demand.

Employment decreases relative to Reference in line with the decrease in real GDP. Level decreases are largest in employment-intensive sectors such as Services and Manufacturing as they employ a larger number of workers per unit of GDP produced. In per cent, the largest declines in employment are in Mining and Manufacturing. Employment increases are, however, experienced in some sectors due to increased production in the case of agriculture and a shift to using more labour relative to capital due to the rising cost of capital relative to labour. In terms of employment sub-categories, most job losses are experienced in rural areas (more than 50 % by 2050). Agriculture, mining, and manufacturing employ more than 50 % of its workers from these regions. Job losses are concentrated among workers with primary school or less education (i.e., uneducated and primary), with 90 % of total job losses coming from these two labour groups. This trend is reflected in rural and urban areas, although uneducated and primarily educated job losses account for over 90 % in rural areas.

Household distributional impacts

Table 2 presents the change in household income by representative group. The change in income includes returns to production factors (i.e., labour, land and capital) and enterprise income - transfers do not change between the modelled scenarios. In line with GDP and employment impacts, household income decreases under mitigation relative to Reference, with declines larger under the Ambitious than Moderate scenario.

Urban incomes are more negatively affected by the impacts of mitigation than rural incomes. This result is driven by the sources of income for respective households. Urban households receive a large portion of their incomes from enterprise returns (non-agriculture capital investments) and urban employment. In contrast, rural households are more dependent on land, agricultural capital, and rural labour as sources of income. Enterprise incomes experience the largest decrease in returns relative to other production factors, followed by labour incomes in urban areas. Both these production factors are more intensively used in the Services, other industries (Electricity, Construction and Water) and Non-Food manufacturing sectors. Rural labour is more intensively used in the Agriculture, Mining and Food manufacturing sectors. In rural areas, non-farm households are marginally more negatively affected than farm households, as non-agriculture sectors experience larger declines in employment and wages. Income declines are marginally more severe for lower-income households due to their dependence on enterprise income. Low-income households receive more income from low-skilled labour, which is concentrated in agriculture and food manufacturing.

Declines in household incomes translate into decreases in real household expenditure, as illustrated in Table 3. In line with income changes, urban households are more negatively affected than rural households, and rural non-farm households experience larger expenditure declines than rural farm households. However, Expenditure decreases are larger than income decreases as price changes are included. Overall, prices increase under mitigation. Expenditure changes across quintiles are aligned with income changes for rural households, i.e. high-income households are more negatively affected. In urban areas, however, low-income households experience larger expenditure declines than higher-income households, as the latter group can reduce savings by more than the former to supplement declines experienced in income.

Under both the Moderate and Ambitious scenarios, poverty increases. In the short term, by 2030, the rise in poverty will be concentrated in rural areas, while in the longer run, by 2050, poverty increases will be larger in urban regions (using the upper poverty line). The severity of poverty also increases under mitigation, with the poverty gap index and squared poverty gap index rising in 2030 and 2050. The level of inequality remains relatively unchanged across the scenarios (see Table 4).

Impacts of climate financing

In this section, we consider the impacts of climate change mitigation actions under conditions where investments in the power sector are financed through foreign climate financing in the form of grants. Specifically, we compare changes in the impacts on GDP, employment,

Table 2
Percentage change in household income relative to the reference case.

		Household quintile				
		1	2	3	4	5
NDC Moderate	Rural: Farm	−1.25	−1.25	−1.26	−1.29	−1.32
	Rural: Non-rural	−1.30	−1.31	−1.33	−1.36	−1.38
	Urban	−1.47	−1.47	−1.49	−1.46	−1.47
NDC Ambitious	Rural: Farm	−1.83	−1.83	−1.86	−1.91	−1.97
	Rural: Non-rural	−1.89	−1.92	−1.97	−2.02	−2.08
	Urban	−2.18	−2.19	−2.24	−2.23	−2.26

Source: GHATIM-GE.

Table 3
Percentage change in total real household expenditure relative to the Reference case.

		Household quintile				
		1	2	3	4	5
NDC Moderate	Rural: Farm	−1.42	−1.45	−1.44	−1.48	−1.49
	Rural: Non-rural	−1.67	−1.69	−1.76	−1.77	−1.82
	Urban	−2.53	−2.24	−2.21	−2.21	−2.11
NDC Ambitious	Rural: Farm	−1.95	−1.99	−1.98	−2.05	−2.09
	Rural: Non-rural	−2.23	−2.27	−2.38	−2.42	−2.50
	Urban	−3.30	−2.99	−2.98	−2.99	−2.92

Source: GHATIM-GE.

Table 4
Change in the number of people living below the Food, Lower and Upper poverty lines.

	Moderate			Ambitious		
Poverty line	Food	Lower	Upper	Food	Lower	Upper
Total	6148	774	27,167	6800	6431	47,975
Rural	647	774	2817	1299	774	4444
Urban	5501	0	24,350	5501	5658	43,531

Source: GHATIM-GE.

poverty, and inequality to the earlier scenarios where mitigation was financed domestically.

Overall, we see a positive impact on real GDP and employment when power sector mitigation efforts are financed through international support (see Table 5). Access to foreign funds reduces financing costs experienced when funding mitigation solely through local resources. At the sector level, almost all sectors record gains in real GDP except for Mining and Manufacturing. As before, sub-sectors in Mining and Manufacturing are directly affected by the changes in power sector technologies, specifically the decreased use of crude oil and petroleum. Economic gains are reflected in employment levels, which increase under power mitigation with climate financing. However, The Mining sector sees lower employment levels relative to Reference, although less negative than without climate financing, as decreases in crude oil production are insufficient to offset gains in the rest of the sector.

Employment gains are concentrated in urban areas, although gains are also experienced in rural areas. The larger increase in urban employment results from stronger growth in manufacturing (excluding petroleum refineries), Other industries and Services. Within urban and rural areas, more jobs are created for lower-educated workers (lower-educated workers are a larger share of total employment). However, per cent increases are higher for middle and higher-educated workers—the increase in employment and the improvement in sector activity results in increased household income and expenditure. As a result, the poverty level decreases relative to Reference across all three poverty lines considered (see Table 6). This contrasts with findings from Campagnolo and Davide (2019), who report increased poverty in Ghana. This difference in results may be due to the difference in focus – where the current study considers mitigation considerations in a particular sector while Campagnolo and Davide (2019) focus on country-level emission targets. However, a moderate increase in expenditure-based inequality is experienced.

Discussions and conclusions

The study highlights the macroeconomic implications and distributive effects of the mitigation strategies Ghana currently has in place, which constitutes the reference case. This scenario captures the moderate and ambitious nature of the mitigation under two different financing options.

Table 5
Percentage change in sector GDP and employment relative to Reference by 2050 with foreign climate financing.

	Real GDP (%)		Employment ('000 s)'	
	NDC Moderate	NDC Ambitious	NDC Moderate	NDC Ambitious
Total GDP	4.6	4.0	1435	1463
Agriculture	3.8	3.7	482	520
Crops	2.6	2.6	402	433
Mining	−1.5	−3.7	−7	−18
Manufacturing	2.7	1.5	367	377
Food	6.8	6.8	229	245
Other	1.1	−0.6	138	132
Other industry	6.9	6.6	102	114
Services	5.5	5.1	491	469

Source: GHATIM-GE.

Overall, reducing emissions in the power sector negatively impacts economic growth. The reduction in GDP below the reference case ranges from 0.4 % - 3.3 % under the moderate case to 0.9 % - 4.4 % in the ambitious case in the short to long run. These significant reductions observed are driven by the crowding out of funding for the real sector due to the diversion of domestic funds to the power generation sector to provide the required investment in the power generation sector. The most affected sectors of the economy are the mining and manufacturing sectors, mainly driven by significant declines in the production of natural gas and crude oil and the manufacturing of food, particularly in the meat sector. However, with funding from foreign sources, the GDP losses are offset with GDP increasing between 2.7 % to 4.6 % under the moderate emission reduction scenario and from 2.4 % - 4 % in the long term under the ambitious scenarios. At the sectoral level, manufacturing and mining sectors recover, although the mining sector is slower to recover in the long run. These findings suggest that financing mitigation activities in the power sector using foreign funding sources makes it less costly for Ghana to transition to low emissions.

The negative impacts of mitigation on GDP are reflected in the job losses with larger declines in employment in 2050, where the economy becomes more employment-intensive than in 2030 due to the increased contribution of manufacturing and services in the country 2050, rural areas experience the majority of the job losses due to their involvement in the agricultural sector which also experiences a significant decline in growth. The employment declines are exceptionally high among workers with less education in rural and urban areas, resulting in wage declines for lower-skilled workers, particularly those in the urban areas. Similar to the reversal in the GPD growth under foreign financing, we observe significant gains in employment with concentrations in the urban areas. This is explained by the large employment in the manufacturing and services sectors. However, by 2050, we find significant employment in the rural areas as well among workers with relatively less education experiencing these gains.

With respect to distributive impacts, findings suggest that mitigation in the power sector is associated with larger negative impacts on rural households, particularly for farm households, than non-farm households. In the long term, however, both rural and urban households experience declines in incomes as a result of the ambitious mitigation efforts. The results show climate change mitigation is associated with increased poverty, with large concentrations in rural areas by 2030 and large concentrations in urban areas by 2050. There is no change in inequality across the moderate and ambitious scenarios considered when mitigation is financed through domestic resources. Poverty is significantly reduced under foreign financing, although inequality rises marginally under all scenarios.

In interpreting these results, it is important to acknowledge some of the study's limitations. First, in the economic analysis, the current study does not account for any other benefits associated with the decreased emissions, such as improvement in air quality, which may have health benefits and, therefore, reduced medical expenditure for households and the government, which will ultimately have positive impacts on productivity. In addition, it is important to note that mitigation costs may be lower if other sectors are also considered. For instance, cheaper mitigation options may exist in other sectors, reducing the need for such significant reductions in emissions from the power sector. Given that the current work considers only mitigation strategies to reduce emissions, future work could consider a combination of adaptation and mitigation strategies. An expansion of the models could be considered to account for the impacts of mitigation strategies at a more disaggregated level, such as the district level, to guide more effective policymaking. Also, in this current study, we consider two extreme financing options- domestic or foreign. Future studies could explore the financing options that combine both sources of financing to find the most optimal option that is feasible for the country.

Table 6
Reductions in the number of people living below the Food, Lower and Upper poverty lines.

	Moderate			Ambitious		
Poverty line	Food	Lower	Upper	Food	Lower	Upper
Total	−206,818	−206,818	−301,742	−316,249	−316,249	−449,257
Rural	−47,833	−47,833	−69,871	−74,126	−74,126	−104,260
Urban	−158,986	−158,986	−231,870	−242,123	−242,123	−344,996

Source: GHATIM-GE.

CRediT authorship contribution statement

Monica Lambon-Quayefio: Writing – review & editing, Writing – original draft, Data curation. **Bruno Merven:** Writing – original draft, Validation, Methodology, Formal analysis, Data curation. **Alison Hughes:** Writing – original draft, Methodology, Formal analysis, Data curation. **Faaiqa Hartley:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation. **Robert Darko Osei:** Writing – review & editing, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Characteristics of existing power plants.

Existing power plants						
Power plant	Fuel Type	Capacity (M.W.)	Efficiency	Capacity factor	Last year of operation	First year of operation
Hydro power plants						
Akosombo	Hydro	900	100 %	0.529	2055	1965
Bui	Hydro	360	100 %	0.334	2063	2013
Kpong	Hydro	140	100 %	0.698	2052	1982
	Sub-total	*1400*				
Thermal power plants						
KTPP	Oil	200	30 %	0.926	2030	2016
Karpower (power rental)	HFO	450	30 %	0.926	2039	2014
Takoradi International Company (TICO)	Oil/NG	320	29 %	0.904	2024	2009
Cenpower	Oil/DFO	340	29 %	0.896	2044	2019
Takoradi Power Company (TAPCO)	Oil/NG	300	30 %	0.847	2019	1997
CENIT Energy Ltd. (CEL)	Oil/NG	100	30 %	0.866	2039	2014
Tema Thermal Plant1 (TT1P)	Oil/NG	100	30 %	0.926	2026	2008
Tema Thermal Plant2 (TT2P)	Oil/N.G.	70	30 %	0.926	2026	2008
Amandi	Oil/NG	190	30 %	0.926	2046	2021
Sunon–Asogli Power (SAPP)	NG	520	30 %	0.926	2039	2014
AMERI	NG	230	30 %	0.926	2039	2014
AKSA	HFO	350	30 %	0.922	2039	2014
Early power*	Gas/LPG	140	30 %	0.922	2046	2021
	Sub-total	*3310*				
Renewables *(excl. Large hydro)*						
Ayitepa Wind Farm	Wind	225	100 %	0.548	2043	2023
VRA Solar (Navrongo)/BXC/VRA/Bui	Solar	67.5	100 %	0.344	2032	2013
	Sub-total	*292.5*				

Table A2
Characteristics of new power plants.

New power plants					
Power plant	Capacity (M.W.)	Efficiency	Capacity factor	Capital Cost (US$/kW)	Fixed O&M (US$/KW/a)
Hydro power plants					
Tanoso Hydro	56	100 %	0.50	2500	46
Sedukrom Hydro	17	100 %	0.50	2500	46
Lanka Hydro	95	100 %	0.50	2500	46
Kojokrom Hydro	30	100 %	0.50	2500	46
Joromo Hydro	20	100 %	0.50	2500	46
Jambito Hydro	55	100 %	0.50	2500	46
Hemang Hydro	186	100 %	0.42	2500	46
Awiasam Hydro	50	100 %	0.50	2500	46
Asuaso Hydro	25	100 %	0.50	2500	46
Ankobra Hydro	140	100 %	0.50	2500	46
Abatumesu Hydro	50	100 %	0.50	2500	46
Ntereso Hydro	64	100 %	0.50	2500	46
Pwalugu Hydro	96	100 %	0.44	3000	46
Kulpawn Hydro	36	100 %	0.53	3000	46
Juale Hydro	87	100 %	0.53	3000	46
Daboya Hydro	43	100 %	0.52	3000	46
Wind Zone 005	419	100 %	0.40	2150	79
Wind Zone 004	1764	100 %	0.29	2180	79
Wind Zone 003	1465	100 %	0.31	2186	79
Wind Zone 002	415	100 %	0.32	2179	79
Wind Zone 001	1259	100 %	0.29	2171	79
Solar PV Zone 005	11,488	100 %	0.20	1565	28
Solar PV Zone 004	2120	100 %	0.19	1511	28
Solar PV Zone 003	8156	100 %	0.20	1501	28
Solar PV Zone 002	2947	100 %	0.19	1553	28
Solar PV Zone 001	14,129	100 %	0.20	1514	28
	Maximum/year				
Generic Diesel Centralized	500	35 %	0.89	1086	33
Generic HFO	500	35 %	0.89	1086	33
Generic Gas Open Cycle	500	35 %	0.92	795	24
Generic Gas Combined Cycle	500	58 %	0.92	1014	30
Generic Coal w CCS	500	28 %	0.92	7478	224
Generic Coal	500	39 %	0.92	3739	112
Generic Hydro Small	500	100 %	0.50	3000	90
Generic Bagasse	500	26 %	0.82	2412	77
Generic Wood	500	26 %	0.82	2412	77
Generic Geothermal	500	100 %	0.77	4000	120
Generic P.V. system (rooftop - urban)	500	100 %	0.30	1600.00	24
Generic P.V. system (rooftop - commercial buildings)	500	100 %	0.30	1489.00	23
Generic P.V. system (rooftop - rural)	500	100 %	0.30	3232.00	145
Generic battery				1500	48

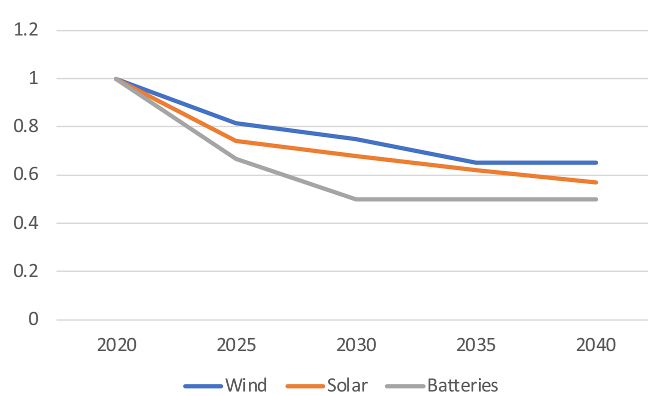

Fig. A1. Technology learning on renewable plants and batteries.

Table A3
Fuel prices ($/GJ).

	2020	2025	2030	2035	2040
Bagasse	0.001	0.001	0.001	0.001	0.001
Diesel	13.6	16.6	19.5	20.7	21.8
Gas	7.4	8.2	9.0	10.1	11.2
HFO	9.3	11.3	13.3	14.1	14.9
Wood	8.5	8.5	8.5	8.5	8.5

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