Integrated Power System Master Plan for Ghana

Volume #1

Executive Summary

November, 2019

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FOREWORD

The 2019 Ghana Integrated Power Sector Master Plan (IPSMP) is an output of three years of work by the Energy Commission and various Ghana energy agencies, with support by the Integrated Resource and Resilience Planning (IRRP) Project. Technical and financial support for the IRRP project was provided by the United States Agency for International Development (USAID) who contracted ICF, a U.S. consulting firm, to implement the project. In 2018, the IRRP team developed the first IPSMP in close collaboration with Ghana energy sector agencies, led by the Energy Commission (EC), Ghana Grid Company (GRIDCo) and the Ministry of Energy (MoEn). This 2019 IPSMP is the first update of the 2018 IPSMP.

The vision of the IPSMP is to plan for a resilient power system that reliably meets Ghana's growing power demand in a manner that supports sustainable socio-economic development.

Both 2018 and 2019 IPSMP highlight significant excess capacity in the country's generation system. The excess capacity, which is expected to persist until mid-2020s, has associated financial implications, such as payment of capacity charges for plants that may not be fully dispatched until demand picks up in the future. Furthermore, the sector's financial difficulties stem from: (a) high cost of fuel used by thermal power plants; (b) gas supply shortages; (c) high payments for installed capacity to Independent Power Producers (IPPs); (d) high distribution losses; (e) low revenue collections by Electricity Company of Ghana (ECG); and (f) non-payment by Government entities. Due to these factors, electricity sector revenues from tariff collection do not cover costs—the revenue gap in 2016 was $794 million, according to a World Bank report published in 2018[1]

In response, the Government of Ghana (GoG) initiated an Energy Sector Recovery Programme (ESRP) in 2018 with the objective of curtailing this financial drain and averting such further occurrence going forward. The ESRP's immediate objective was to provide a clear and comprehensive roadmap of strategic actions, reforms and policies that would instil discipline into the energy sector to ensure financial viability and sustainability. The objectives of the ESRP are very much in line with the recommendations of the 2018 and the 2019 versions of the IPSMP.

The Energy Commission, together with GRIDCo, will continue to lead in updating the IPSMP on a regular basis (at least every two years). The IPSMP, along with the Annual Supply – Demand plans, will form the basis for the development of the power sector going forward.

Ing. Oscar Amonoo-Neizer.

Executive Secretary, Energy Commission

4 November 2019

[1] http://documents.worldbank.org/curated/en/953141527091798128/pdf/Project-Information-Document-Integrated-Safeguards-Data-Sheet-Ghana-Energy-Sector-Transformation-Initiative-Project-P163984.pdf - Ghana - Energy Sector Transformation Initiative Project (P163984)

ACKNOWLEDGEMENTS

The 2019 Integrated Power Sector Master Plan (IPSMP) was updated by the Energy Commission and the Integrated Resource and Resilience Planning (IRRP) team. Financial and technical support were received from USAID, Ghana, through its funding of the IRRP project, which was implemented by ICF[2], a US-based consulting firm.

The Energy Commission and the IRRP team wish to express their gratitude to the USAID Ghana Mission, for sponsoring the IRRP project with support from Power Africa. The feedback received from the USAID's local Energy Team (Mark Newton and Dorothy Yeboah Adjei) during the update of the IPSMP has been very helpful.

The Energy Commission and the IRRP team acknowledge the important role played by officials from the Ministry of Energy in their sustained support for the 2019 update of the IPSMP and the guidance provided to the IRRP Technical Committee.

The IRRP team would like to thank the management and officials of the key stakeholder institutions —VRA, BPA, GRIDCo, ECG, NEDCo, EPC, PURC, EC, GNPC, and GNGC—for their active participation in various activities associated with the updating of the 2018 IPSMP. They allowed their technical staff to work closely with the IRRP team, and provided the necessary data for the power sector modelling. The IRRP Technical Committee (see below) was established from these agencies, and these members contributed their time generously to ensure that the 2019 IPSMP was successfully updated in an inclusive manner. These stakeholder institutions are duly commended. All other stakeholders who provided data and specific suggestions that helped to shape the project and the update of the IPSMP are also duly acknowledged.

Stakeholder Institutions Participating in IRRP Process

Volta River Authority (VRA)
Bui Power Authority (BPA)
Ghana Grid Company, Ltd. (GRIDCo.),
Electricity Company of Ghana (ECG)
National Electricity Distribution Company (NEDCo.)
Enclave Power Company (EPC)
Public Utilities Regulatory Commission (PURC)
Energy Commission of Ghana (EC)
Ghana National Petroleum Corporation (GNPC)
Ghana National Gas Company Ltd. (GNGC)

The 2019 Update of the IPSMP report was based on analysis of Ghana's power system as of the end of 2018 using ICF's power planning modelling tool, the Integrated Planning Model (IPM®). A Core IPM Modelling team (see below for members) was instituted to support the 2019 update, and their contributions to the update is also duly acknowledged.

Finally, the tireless efforts and contribution of the ICF Ghana's IRRP team, sub-consultants, and the short-term technical assistants (STTAs), listed below, were critical to the success of this project and update, and they are all gratefully acknowledged.

[2] www.icf.com

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Volume 1: Decision-Makers' Executive Summary of Integrated Power Sector Master Plan

The Ghana Integrated Power Sector Master Plan (IPSMP) is a subset of the Strategic National Energy Plan (SNEP) and is intended to guide the development of Ghana's future power sector.

The IPSMP was developed through the support of the Integrated Resource and Resilience Planning (IRRP) project, which is an initiative of the Government of Ghana and the United States Government. The three-year IRRP project (May 2016 to September 2019) is being funded by USAID and is being implemented by ICF (a U.S.-based consulting firm). The Energy Commission is the focal agency of the IRRP project, with support and guidance being provided by the Ministry of Energy (MoEn).

The IPSMP study assesses current and future challenges and opportunities in Ghana's power sector and develops a resilient generation capacity expansion plan that adequately meets the electricity demand forecast at the least cost.

The modelling for the IPSMP is based on ICF's proprietary Integrated Planning Model (IPM®), which was selected by the IRRP Technical Committee. The IPM is a dynamic, linear programming model that relies on sectoral and zonal data to simulate the operations of any power system for mid- and long-term planning horizons.

This Executive Summary highlights the following:

(i) Goals and objectives of the IRRP and the IPSMP;

(ii) Key findings and recommendations of the IPSMP;

(iii) Recommendations for future planning and procurement;

(iv) Climate risk and resilience assessment; and

(v) Monitoring and updating the IPSMP.

1 Vision and Objectives of the IPSMP

The primary objective of the IPSMP is to identify a **long-term Least-Regrets power sector resource plan** that will meet Ghana's future electricity demand, through an optimisation of existing and future power plants and other energy systems, as well as transmission capability. The Least-Regrets resource plan is based on an evaluation of the resilience of the Ghana power system to potential risks, including fuel prices and availability, hydrological changes, economic growth, policy and regulatory changes, and climate change.

The vision of the IPSMP is to develop "*a resilient power system to reliably meet Ghana's growing power demand in a cost-effective manner that supports the country's sustainable development*".

The specific objectives that define the course to realising this vision are:

1. Achieve cost-competitiveness in power generation and delivery;
2. Reliably meet local demand and exports in a timely manner;
3. Increase resilience of the power system;
4. Ensure positive economic impacts through job creation and GDP growth;
5. Meet Ghana's local environmental and climate change commitments;

6. Promote and implement sustained energy efficiency and demand-side management (DSM) programmes; and
7. Support secondary objectives beyond current universal access goals (e.g., productive uses of electricity, household-level connection, mini-grids).

The IPSMP vision and objectives are aligned with the Government of Ghana's policies in the power sector, and they were developed in a collaborative process led by the Energy Commission, with support from the IRRP project.

2 Modelling Approach for Determining Least-Regrets Strategy

The selected Integrated Planning Model (IPM®), optimises demand-side options, generation, and transmission options simultaneously, and is well suited for scenario analysis.

To select a robust and resilient solution for expanding Ghana's power sector in the future, several different strategies and sensitivities were developed (see adjacent box). Six different strategies were developed and each of them was tested against 11 different sensitivities (see **Error! Reference source not found.**). Specific results or m etrics from all of the strategy-sensitivity combinations were evaluated to determine the Least-Regrets solution. The set of evaluated metrics were related to cost, resilience, reliability, local environment, land use area used for power generation, and climate change.

A **strategy** is a set of modeling assumptions about policy framework and technology/fuel decisions, which are conditions under Ghana's control.

"Sensitivities" test the performance of the various strategies under changing conditions (e.g., load forecasts, technology cost/availability, fuel and renewable resources), which are not fully under Ghana's control.

ES Figure 1: Strategies and Sensitivities Evaluated for the IPS

S1 Unconstrained	Reference case demand assumptions on demand, technology cost, gas resource availability, RE bounds, TTCs, build 60 MW small hydro, No other technology-specific constraints on build options
S2 Diversify with **Coal**	Reference Case assumptions on demand, technology costs, TTC, build 60 MW small hydro Diversify fuels by building a 700 MW coal power plant in two phases: 350 MW in 2027 and 350 MW in 2030 in South West-GH
S3 Diversify with **Nuclear**	Reference case demand assumptions on demand, technology cost, gas resource availability, RE bounds, TTCs, build 60 MW small hydro Diversify fuels by building a 1000 MW nuclear power plant in two
S4 Diversify Geographically	Reference case demand assumptions on demand, technology cost, gas resource availability, RE bounds, TTCs, build 60 MW small hydro Build a 300 MW combined cycle plant in Ashanti-GH by 2027
S5 Renewable Energy Master	Reference case demand assumptions on demand, technology cost, gas resource availability, RE bounds, TTCs, build 60 MW small hydro Implementation of on-grid utility-scale RE capacities identified in
S6 Enhanced G-NDC's	Reference case assumption on demand, technology costs, gas resource availability, TTCs, build 60 MW small hydro Constrain CO2 emissions to half of unconstrained strategy emissions

#	Sensitivity
0	Reference Assumptions
1	High Demand Growth
2	Low Demand Growth
3	High Fuel Prices
4	Low Fuel Prices
5	Limited Gas Supply
6	Greater Domestic Fuel Supply
7	Limited Water Inflows for Hydro
8	Higher RE Capital Costs
9	Lower RE Capital Costs
10	Lower Capital Cost for Conventional Resources

strategy emissions.

Investment costs (i.e., capital costs to be invested) and the total system costs (future capital, operations and maintenance, and fuel costs) were determined to be the most important criterion in the Ghanaian context. Therefore, the least-cost strategy was evaluated against other metrics, to assess whether it remains a valid strategy for Ghana—i.e., whether the other metrics disqualify the least-cost strategy, or not. If disqualified, the next low-cost strategy would be selected for evaluation.

Key Findings and Recommendations of the IPSMP

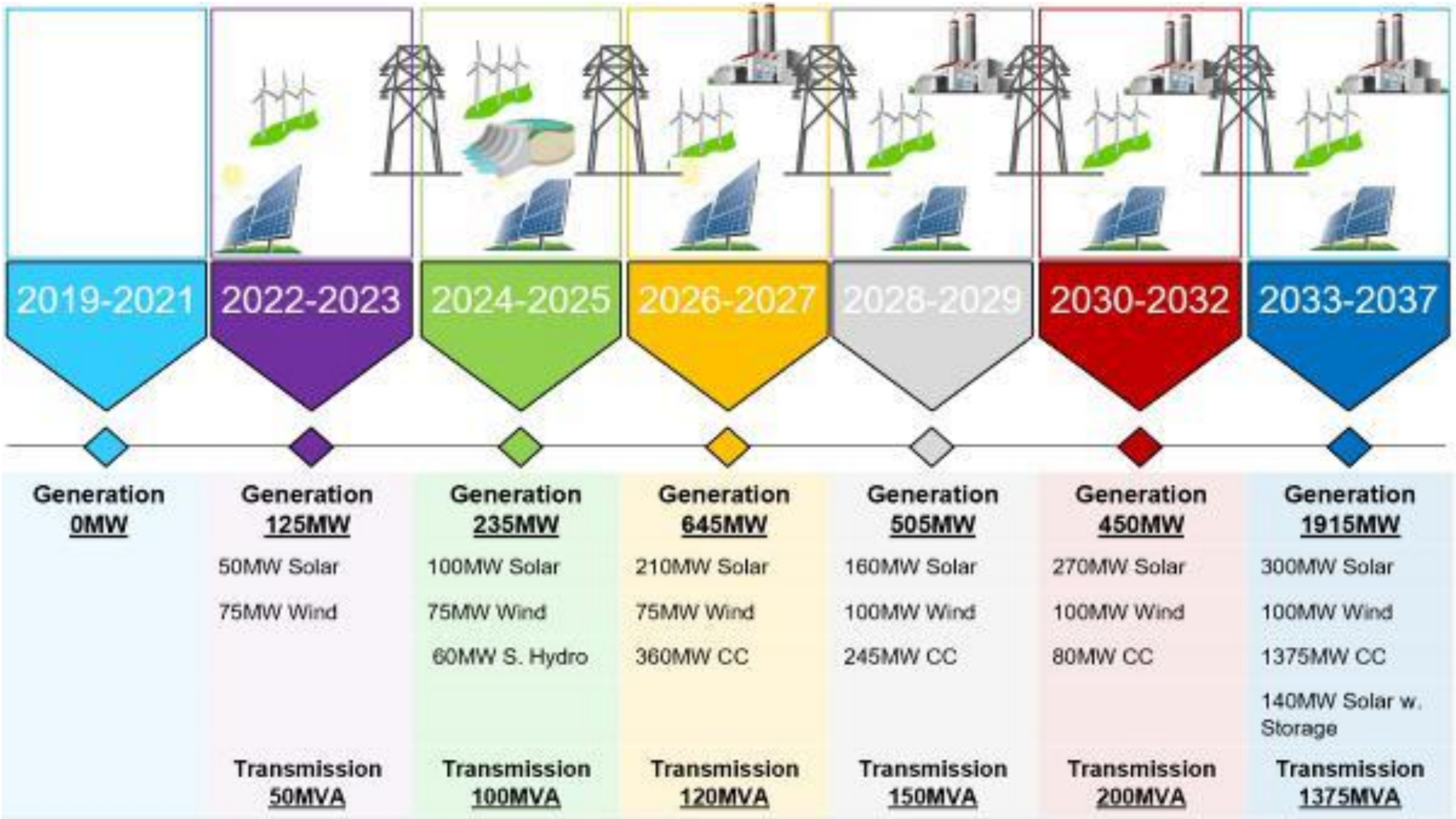
The primary findings from the modelling, and the recommendations associated with these findings are outlined below:

1. **Unconstrained Strategy (Strategy I)** is both the Least-Regrets strategy and the least-cost option**.** The build plan indicated by this strategy is outlined in ES Figure 2.
   - The average cumulative 19-year investment costs are about $370 million USD lower than the second-lowest strategy, which is the Diversify with Nuclear strategy. Natural gas for the power sector is primarily supplied by domestic natural gas resources; however, additional gas imports from Nigeria through WAGP and/or regasified imported LNG becomes necessary by mid-2020s if new domestic gas resources are not developed by that time.
   - Solar PV and wind costs are expected to decline enough to be built economically by the early 2020s. Solar PV generation in the northern region also reduces transmission losses and mitigates voltage stability issues around Kumasi.
   - Additional studies, including ancillary services associated with variable renewable energy (vRE), are needed to fully assess the impact of greater (or lesser) vRE penetration on wholesale electricity costs, in light of policy and cost decline of specific technologies.
   - Ghana's Wholesale Electricity Market is expected to support the provision of ancillary services.
   - Energy efficiency measures could reduce the Reference case power demand by nearly 7% in 2030, purely due to customers making economic decisions to save money by deploying energy-efficient lighting, air-conditioners, and industrial motors. Increased efficiency reduces consumer costs and engenders a more productive economy.

Recommendation 1

- Prioritise the use of indigenous resources (small hydro and other renewables, as well as indigenous natural gas) in power generation.
- Develop new competitively procured solar PV and wind capacity in a slow and gradual manner to increase RE penetration and increase know-how on integration of variable RE plants.
- Build dispatchable small hydropower plants capable of providing additional non-power benefits (such as irrigation, river transportation, flood control, fisheries, etc.).
- As prices decline, consider solar PVs with storage for the middle-to-north of the country, to enhance grid stability.
- Build biomass plants as part of a Least-Regrets strategy, as they could also provide additional economic benefits and contribute to grid stability.
- Continue to promote energy efficiency uptake to save consumer costs in the street lighting, commercial, industrial, and residential sectors through consumer awareness, access to low-cost finance, and implementation and enforcement of standards and building codes.

ES Figure 2: 2019 Least-Regrets Generation and Transmission Additions (Reference Case Demand)

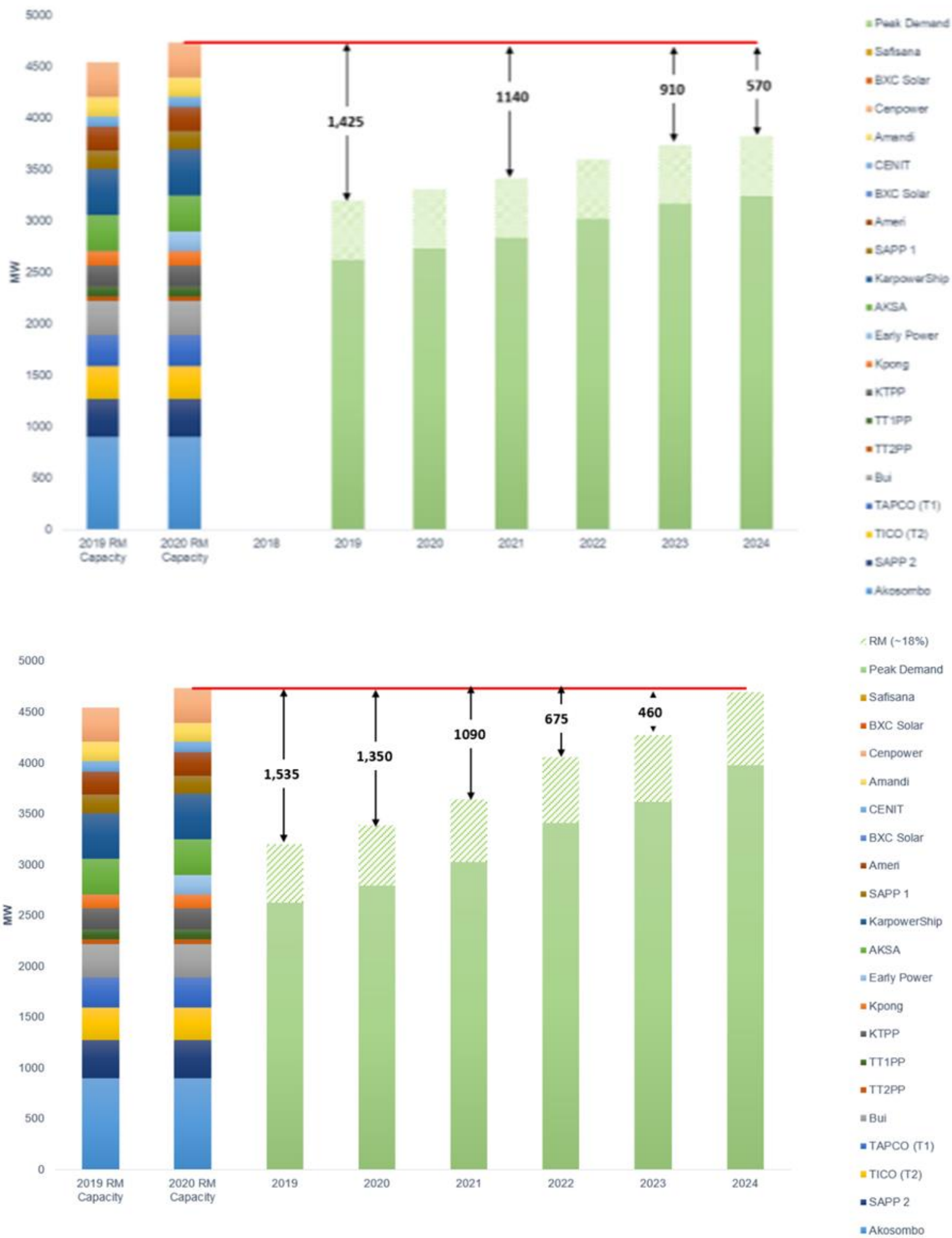


2. There is currently an overcapacity of generation available to the grid (see ES Figure 3) that will persist beyond the end of this decade.
   - Net-dependable capacity, as of December 2018, was 4,492 MW; the current recorded peak was 2,525 MW in December 2018.
   - About 936 MW of new capacity (Cenpower, Early Power, Marinus and Amandi) is currently under construction and is expected to come online by the end of 2020, at which time the net-dependable capacity is expected to be about 5,428 MW.
   - Expected Reference Case peak demand, including a 20% reserve margin, is more than 1,100 MW from 2019 to 2022. Even under a high-case scenario, there will be significant excess of capacity by 2023 (see ES Figure 3).
   - The key constraint in the system is the availability of reliable fuel supply for these existing and under-construction power plants.
   - Fixed capacity charges for existing and under-construction plants will have to be paid by utilities (through consumer tariffs), whether or not these existing plants are dispatched, and therefore dispatch decisions need to be solely based on cost of generation.
   - Despite the current over-capacity in the short-term, developing and installing *competitively procured* solar PV capacity in the range of 20-50 MW is consistent with the Least-Regrets strategy, and will not significantly affect end-user tariffs.
   - New solar PV and wind power plants need to be economically competitive with natural gas-based power plants in the long-run. Therefore, the economics of renewable energy technologies is affected by the delivered cost of natural gas. The capital cost of new solar PV and wind plants should be low enough to displace the marginal cost of generation from gas-based power plants.

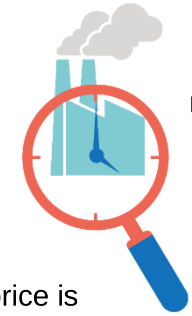
Recommendation 2

- Do not build additional conventional plants beyond the ones under construction until the mid-2020s.
- Delay implementation of any other conventional plants (e.g., Jacobsen, Rotan) such that they come online by 2025.
- Timing for new power plants may be influenced by whether TAPCo would be retired or refurbished, and the timeframe for the refurbishment.
- Start approvals for procurement and construction for these additional plants in the early 2020s so that plants will be built in time.
- Implement the wholesale electricity market, as soon as possible, to increase dispatch efficiency and lower generation costs.
- Evaluate and implement options to increase natural gas supply reliability for existing and under-construction power plants.
- Continue to support development of competitively procured RE projects.

ES Figure 3: Medium-Term Supply-Demand Balance for Reference Electricity Demand (top) and High Case Electricity Demand (bottom) in MW



3. The need for conventional power plants is dependent on the amount of installed RE capacity, EE penetration, and expected demand growth in the future.



   - From the mid-2020s to early 2030s, 400–1100 MW of thermal capacity is needed, and an additional 500–1300 MW is needed to meet meet rising demand in the mid-2030s.
   - These thermal capacity needs can be met by either coal and/or gas plants, but these technologies tend to displace each other.
   - Coal power is more attractive under domestic gas scarcity or high liquefied natural gas (LNG) prices, but if the weighted domestic gas price is below $9-10/MMBtu, gas plants are favoured.
   - Nuclear power is an option beyond 2030, but its development is dependent on policy and economics. Nuclear plants are more expensive to build than coal or gas plants, and require greater regulatory oversight.

Recommendation 3

- Assess demand growth, taking into consideration the impact of Energy Efficiency (EE) and demand side management (DSM), for the next IPSMP update (in 2021) to determine the specific timing for new conventional power plants.
- Reduce new capacity for gas and/or nuclear, if coal-based power is selected by policy; coal-power is, however, not in the Least-Regrets Portfolio for Ghana.
- Assess the broader macro-economic and environmental implications of building a coal or a nuclear power plant before taking a policy decision.

4. Additional transmission builds and/or new local generation capacity is needed beyond the mid-2020s to improve grid stability and reliability, particularly in the Middle Belt and NEDCO regions.
   - Transmission builds lower overall system cost and allows for greater export opportunities.
   - Reliability improves upon completion of current transmission projects including the 330kV Aboadze-Prestea-Kumasi-Tamale-Bolga line.
   - Integrating variable RE capacity up to 10-15% of total system capacity improves reliability of supply in the northern part of the country during off-peak hours, and reduces system losses.

Recommendation 4

- Expedite the construction of the A4BSP substation around Pokuase.
- Conduct additional transmission analyses to confirm specific transmission builds and improvements in the 2020s, particularly towards the Middle Belt
- Facilitate the integration of variable REs into the grid in the northern zone through use of modern technologies and operational changes.
- Give more attention to the proposed project to close the eastern corridor loop from Kpandu-Kadjebi to Yendi through Juale (with or without the Juale hydropower plant) to increase reliability in the NEDCo zone.

5. The implementation of the TTIP coupled with the relocation of the Karpowership to the Western Region has provided an opportunity to drastically reduce the financial obligations under the Sankofa take-or-pay agreement.
   - Without the reverse flow arrangement, gas plants in the east (Tema power enclave) will continue to have fuel insecurity, while plants in the west will be under significant pressure to maintain high operational availability to utilise the Sankofa gas.
   - Beyond 2023, however, with additional plant builds, gas supply from Sankofa, TEN, and Jubilee will not be sufficient to fully meet gas demand for power generation (east and west together). Consequently, additional gas supply is needed to support power plants.
   - Additional gas supply for plants in the Aboadze enclave becomes necessary by the mid-2030s, which can be met through new domestic supply or re-gasified LNG (which could be piped from the east, subject to transportation costs).

Recommendation 5

- A LNG regasification and storage terminal might still be relevant to increase gas supply security, in case domestic gas interruptions (due to maintenance or unplanned outages). However, gas delivered from such an LNG terminal will have higher gas prices
- Consider liquid fuels contracts for plants in Tema enclave, taking into account potential impact of additional gas supply from Sankofa and LNG.

3 RECOMMENDATIONS FOR FUTURE PLANNING

Planning should be more collaborative among the key players in the power sector. In the past, planning was carried out in "silos" and with different sets of assumptions, data sets, planning horizons, and technical analyses.

As such, the current Technical Committee for the Annual Supply – Demand Planning Process should be maintained and renamed **Power Planning Technical Committee (PPTC).** The standing **PPTC** (to be formed by the Ministry of Energy, in coordination with the Energy Commission) should be composed of representatives from EC, GRIDCo, VRA, BPA, ECG, NEDCo, EPC, PURC, MoEn, EPA, MESTI, MoF, GNPC (to provide updates on fuel issues), GNGC, NPI, and co-opted members as needed. The PPTC should be **jointly chaired** by the Energy Commission and GRIDCo. The Energy Commission would lead the longer-term SNEP and IPSMP update process within the PPTC, and GRIDCo (as the System Operator) would lead the Annual Supply – Demand Plans. This planning approach is consistent with both EC's and GRIDCo's statutory mandates.

The MoEn should continue to provide sector policy direction and a focused supervisory oversight on the Energy Commission for implementing the SNEP and IPSMP recommendations.

The Energy Commission should ensure regular and close monitoring of adherence to Annual Supply – Demand Plan and the longer-term SNEP and IPSMP plans' formulation, progress of timely execution of study recommendations, and scheduled updates of plans

The PPTC would have a specific mandate and would consult with other stakeholders (e.g., National Development Planning Commission, Association of Ghana Industries, Ghana Institution of Engineering, Chamber of Mines, academia, and civil society organisations), in the review of the IPSMP as well as the Annual Supply – Demand Plan.

Recommendation 6

- Establish a PPTC to be a one-stop shop for power sector planning in Ghana, which should be jointly chaired by Energy Commission (for long-term planning) and GRIDCo (for short-term annual and operational planning).
- The MoEn should provide sector policy direction and oversight.
- The Energy Commission should monitor adherence to formulation, execution, and updates of plans.
- PPTC should update modelling inputs with stakeholder inputs on a regular basis, and develop updates for IPSMP and Annual Supply – Demand Plans.

4 Recommendations for Future Procurement

Least-cost generation is best achieved through procurement of investment in new generation and transmission by competitive bidding using a well-structured procedure to guide participants.

Future procurements of additional generation expansion and transmission to meet demand should be based on the supply-demand figures in the plans produced by the PPTC. The timing, location, and size of the additional generation, as well as the type of technology or resource used, should also be consistent with the plan to ensure that the capacity procured meets demand without creating over-capacity.

All future procurement of power plants for the regulated market should be open, competitive and subject to approval by the regulators. This will ensure that the procurement is aligned with the recommendations of the IPSMP, the Annual Supply – Demand Plans, and the rules of the wholesale electricity market. The Energy Commission, therefore, needs to review and update its “Framework for the Procurement of Electric Power Generation from Wholesale Suppliers of Electricity (June 2010)”.

In order to avoid periods of under-supply, the Energy Commission should be able to initiate a competitive procurement process; and both regulators need to provide their no-objection to all future procurements by the regulated entities.

The Energy Commission should also use its licensing mandate to ensure that capacity procurements are consistent with the recommendations of the IPSMP and Annual Demand – Supply Plans.

Bulk customers planning to procure their own supplies to meet their demand should provide information on their demand forecast and planned supply sources to the EC and PURC, to support the work of the PPTC in developing the IPSMP and Annual Supply – Demand Plans.

Recommendation 7

- All future procurement of power plants connected to the grid should be based on the recommendations of IPSMP and Annual Demand – Supply Plans.
- Competitively procure new transmission systems based on a Transmission Master Plan that is consistent with IPSMP results.
- Location, size, timing, and type of technology or resource for future procurement should all be laid out without creating over-capacity.
- Bulk and direct customers, who are in the deregulated market, may procure power generation on their own.
- Regulated DISCos should seek no-objection from the regulators, Energy Commission, and PURC to proceed with an acceptable competitive procurement process.
- The design of the Wholesale Electricity Market (WEM) and the development of the market rules and their implementation need to be expedited to provide price signals for the need and location of new generation and any required ancillary services in the long term.

5 Other Recommendations

The following recommendations on demand forecasting, transmission, and distribution are highlighted here for focused attention in the short term.

Demand

- Enhance and institutionalise the current Annual Supply – Demand forecasting activity with emphasis on strong collaboration among the various planning institutions, the use of better modelling tools, and the collection of more granular data at the DISCo and bulk customer levels, using standard data collection templates.
- Formulate and implement new policies and programmes that support the deployment of energy efficiency and conservation measures (e.g., the use of light-emitting diode [LED] lamps, more efficient air conditioners, and fridges/deep freezers) to help decrease the growth rate of electricity demand, and keep carbon footprints down while helping businesses and homes to save money.
- Continue and enhance collaboration between the various agencies (e.g., GRA/Customs, the Energy Commission, and Ghana Standards Authority) that implement DSM measures to effectively enforce the ban/control of entry of substandard or non-energy efficient appliances at the country's points of entry.

Transmission

- Update the 2011 Transmission System Master Plan, as the model assumptions behind the 2011 study have now changed.
- Upgrade the lines from the Western region (Aboadze) to the Middle Belt area, and the link between Tema/Akosombo and Aboadze to address transmission constraints and increase the reliability of the transmission network.

- Adopt, as a matter of policy, double circuits for high-voltage transmission lines to mitigate future right-of-way constraints in all-new high-voltage transmission and sub-transmission lines.
- Carry out an assessment of the aggregate effect of all variable REs (wind and solar) currently connected to the grid, to help in recommending mitigation measures for future variable RE projects.
- Arrange to procure and install weather forecasting stations in collaboration with the Ghana Meteorological Agency at the System Control Centre (SCC), GRIDCo substations, and request that RE developers install same at their RE plant sites, to help SCC predict the output of the various REs connected to the grid and assist in the overall dispatch process.

Distribution

- Utilise information gathered from smart meters and automatic meter readers (AMR) to implement options to reduce commercial losses and improve the collection rate of the distribution companies. Analyses of the data will also provide the most recent data from these customers for future demand forecasting.
- There is the need for improved coordination between the Ministry of Energy and the distribution utilities in the extension of the grid to new communities and the connection of new customers.
- Improve inventory management of meters to avoid the situation where some customers are put on flat rate.
- The Energy Commission should consider reviewing relevant sections of the GRID Code to enable the use of higher voltages, e.g., 69 kV instead of 33 kV for sub-transmission lines to reduce technical losses.
- Expand the scope of 2017 ECG's Accra Reliability Assessment study to cover more regional capitals and other ECG service areas to improve distribution planning.
- NEDCo needs to expand the scope of load flow analyses carried out in Tamale (2016) to include heavy load centres like Sunyani, Techiman, Wa, and Bolgatanga and other towns and cities to improve distribution planning.
- Develop an integrated SCADA system across all utilities in Ghana.
- The deployment, operation and maintenance of solar PVs at the 33-kV and 11-kV voltage levels should be undertaken by the DISCo. However, GRIDCo should be informed or notified from planning, construction, operation and maintenance stages since each stage has impact on the NITS and dispatch decisions. Large (>20 MW) solar projects should be connected to the transmission grid at higher voltages.
- Carry out studies to determine localities where roof-top solar PV installations can result in significant technical loss reduction and improve value to the utilities.
- Distribution utilities should coordinate with MoE and harmonize GIS data collection and its use for planning, operations, and maintenance of distribution service assets, in order to save costs and avoid duplication of effort.

Regulations

- PURC must adopt a rate-setting methodology that is transparent and easily comprehensible, to minimise public outcry at times of tariff reviews. Quarterly adjustments should be followed strictly and transparently to avoid big jumps in the rates over time, which then allows businesses to plan their finances in a more predictable manner. All subsidies that affect implementation of the quarterly adjustments should be explicitly specified and made public.
- All regulatory levies and fees should be publicly announced.

6 CLIMATE RISK ASSESSMENT AND MANAGEMENT

Climate change is already impacting Ghana, and greater impacts are anticipated in the future. By mid-century, Ghana's average annual temperature is projected to increase by 1.2 to 1.7°C.[3] Change in annual precipitation is more uncertain, as models disagree on the signs of change. Projections for change in annual runoff and consecutive dry days (a proxy for drought) are mixed and projected to change only minimally. There is more certainty in projections in extreme rainfall, with the vast majority of models projecting increases throughout the country. Sea level rise is also projected to increase by around 0.4 to 0.7 metres by mid-century.[4]

To assess the potential impacts on the power system, the IRRP project conducted an analysis of these potential changes and considered the impacts on the power sector at the zonal level. Direct and indirect impacts were determined, including implications on power planning, and risks to transmission and distribution infrastructure - especially for assets located in low-lying coastal areas that may be exposed to rising sea level, storm surge heights, and increases in extreme rainfall and temperature (see ES Figure 4).

[3] This represents the multi-model ensemble mean for RCP 4.5 ("low") and 8.5 ("high") scenarios, from KNMI Climate Explorer, relative to the 1986-2015 reference period.

[4] Figure 13.20 in Church, J., P. Clark, A. Cazenave, J. Gregory, S. Jevrejeva, A. Levermann, M. Merrifield, G. Milne, R. Nerem, P. Nunn, A. Payne, W. Pfeffer, D. Stammer and A. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T., D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom.

ES Figure 4: Summary of Relative Risk of Climate Stressors to Ghana's Power System

Climate Stressor	Generation			Transmission & Distribution	Demand
	Hydro	Thermal	Renewables		
Extreme Rainfall, Flooding, & Sedimentation	High	High	High	High	Low
Drought	High	Med	High / Low*	Med	High
Sea Level Rise & Storm Surge	Low	High	Med	High	Low
Temperature	Med	Med	Med / Low**	Med	High
Water Flow, Volume, & Timing	High	Low	High / Low*	Low	Low

*Biomass is highly sensitive to drought and rainfall/flow variability/timing, while solar and wind have lower sensitivity
**Biomass has a higher level of sensitivity to temperature than solar and wind

Taken in combination, projected increases in extreme weather (drought, flood, or heatwaves) have the greatest potential to impose negative impacts because they are likely to increase demand while diminishing generation (in particular, hydropower) as well as transmission and distribution capacity.

To manage the impact of these climate stressors, a variety of adaptation measures can be applied. Measures range from no-regrets actions, which are proactive and beneficial to the power system regardless of climate change, to climate-justified measures, which include actions that might only be justifiable if expected changes in climate materialise.[5] Types of adaptation measures include policy and planning, operation and maintenance, technological, and structural measures. The specific adaptation options for demand, generation, and transmission and distribution infrastructure are discussed in the Appendix of this report.

Recommendations on climate resilience:

- The least regrets 'Unconstrained' strategy involves increased investment in renewables, which can help Ghana enhance energy security and curb greenhouse gas (GHG) emissions. Yet, renewable resources are also at risk of underperformance or disruption due to a range of climate stressors. Therefore, it is important to assess the sensitivity of renewables to future climate risks, particularly for small hydropower plants.
- There are significant uncertainties regarding changes in future precipitation, land use, and water and power demands, which have major impacts on future hydropower reliability in Ghana. Additional analyses in future IPSMP updates should test the sensitivity of hydropower to a broad

[5] World Bank. 2009. "Water and Climate Change: Understanding the Risks and Making Climate-Smart Investment Decisions".

range of future climate changes. This may require a more sophisticated water resources model that can include scenarios of future climate change, water consumption, upstream water use, and reservoir storage and hydropower production. By dynamically coupling the water resources model to the IPM model, one could better understand the ramifications of climate change on hydropower and future performance of the investment strategies.

- Improved understanding of current and potential future coastal flood risk to existing and planned power system assets in proximity to coastal areas (e.g., power plants, substations, and transmission lines) is necessary to improve resilience of the power system.
- Regular updates to the IPSMP should include proactive performance tracking, monitoring of trends and new climate projections, and implementation of adaptation measures over time. Monitoring increases knowledge and understanding of changing climate risks over time, providing critical information on power system performance. These data can then be used to make operational improvements, trigger early warning systems, and improve adaptation investment planning over time.
- Power sector planners should be equipped with the tools and resources needed to navigate the evolving architecture of climate finance, and seize opportunities for accessing finance for mitigation and adaptation in the power sector.

7 Monitoring and Updating of the IPSMP

The Ministry of Energy through the Energy Commission should ensure that the IPSMP is implemented according to schedule and that key metrics that trigger updates to the plan should be adhered to. See ES Figure 5.

The IPSMP has an accompanying Monitoring and Evaluation (M&E) Plan in the Appendix that provides guidance for effective monitoring and updating of the plan. This plan, among others, assigns M&E roles and responsibilities to the relevant stakeholders.

The preferred timeframe for reviewing and updating the plan is every two or three years. The next update is scheduled for 2021 by the PPTC for the 2022 release. The USAID through its West Africa Energy Project will provide the necessary capacity building activities to the PPTC and other staff of stakeholder institutions in 2020, to allow the PPTC (co-chaired by Energy Commission and GRIDCo) lead the process for the 2022 IPSMP update.

ES Figure 5: Monitoring roles of the Ministry and the Energy Commission