Integrated Power System Master Plan for Ghana

Volume #1

Executive Summary

December 6, 2018

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FOREWORD

Electricity, as a versatile form of modern energy, is a critical ingredient for economic growth. Therefore, increasing the availability of, and access to, electricity at an affordable price is a high-priority objective within the national planning processes in many developing countries, including Ghana. A specific and concerted focus on enhancing Ghana's power sector has resulted in significant gains in installed generation capacity, access to electricity (at about 84% as of the end of December 2017) since Ghana's independence.

Planning for the effective development of the electricity sub-sector is considered the single most important activity because it can facilitate sustained economic growth. Consequently, electricity sector planning is paramount to Ghana's overall energy system planning.

The Energy Commission, which was established by the Energy Commission Act 1997 (Act 541), has the statutory responsibility to, inter alia, prepare, review, and periodically update indicative national energy plans, which will provide the framework to ensure that all reasonable energy demands of the economy are met in a sustainable manner.

Prior to the enactment of the Volta River Authority (Amendment) Act 2005, in line with the Power Sector Reforms, the Volta River Authority (VRA) had the mandate to plan specifically for sufficient electricity supply to meet the country's demand and the Electricity Company of Ghana (ECG) and Northern Electricity Distribution Company (NEDCo) had responsibility for power distribution in the country. The Power Sector Reforms acknowledged the need for an independent Nationally Interconnected Transmission System (NITS) and the important role of a national transmission operator (Ghana Grid Company Ltd. [GRIDCo]) in planning for the operation and management of the NITS.

These agencies (Energy Commission, VRA, Bui Power Authority [BPA], ECG, NEDCo, and GRIDCo) have been involved in electricity system planning process in recent years. To address the challenges of the electricity supply shortfall in 2012–2016, the sector Ministry got involved in the procurement of power plants. The power supply shortages were caused by a combination of challenges, which included non-adherence to developed plans, including the 2006 Strategic National Energy Plan (SNEP), erratic supply of natural gas (fuel shortages), low water levels in the hydropower dams due to over-drafting of the reservoir, technical challenges at the thermal plants, and most critically, financial challenges (e.g., inability to pay for gas and liquid fuels imports) in the power subsector.

Therefore, the Ministry of Energy (MoEn) in its draft November 2017 Energy Policy statement called for the development of an Integrated Power Subsector Master Plan that would be developed in a coordinated manner to address the challenges for the development of the country's power sector.

In line with the Energy Policy, this Ghana Integrated Power Sector Master Plan (IPSMP) has been developed jointly by the Ghana energy sector agencies. The ISPMP was led by the Energy Commission and the Ministry of Energy, with support from the United States Agency for International Development (USAID) through the USAID/Ghana Integrated Resource and Resilience Planning (IRRP) project, which was implemented by the U.S. consulting firm, ICF.

The IPSMP is considered as a subset of the SNEP, which is updated by the Energy Commission periodically. The short- to medium-term Annual Supply – Demand plans, which are jointly developed by Ghana Grid Company (GRIDCo) and the Energy Commission as the lead agencies, have also informed the development of the IPSMP.

The vision of the IPSMP is to develop a resilient power system, which reliably meets Ghana's growing demand for power in a manner that supports the country's sustainable economic development.

It is expected that the IPSMP will be updated on a regular basis (at least every three years), and the IPSMP, along with SNEP and the Annual Supply – Demand plans, will form the basis for the development of the power sector going forward.

A. K. Ofosu Ahenkorah, Ph.D.
Executive Secretary
Energy Commission

6 December 2018

ACKNOWLEDGEMENTS

The Integrated Power Sector Master Plan (IPSMP) was developed by the Energy Commission, with financial and technical support from USAID, Ghana, through its funding of the Integrated Resource and Resilience Planning (IRRP) project. The IRRP project is being implemented by ICF[1], a US-based consulting firm. We wish to express our gratitude to USAID Ghana Mission, for sponsoring the IRRP project with support from Power Africa. The feedback received from the USAID's local Energy Team (Waqar Haider, Mark Newton, Dorothy Yeboah Adjei, Richard Chen, and Robert Buzzard) has been very helpful during the IPSMP development.

The Energy Commission and the IRRP project would like to acknowledge the important role of the Ministerial officials from the Sector Ministry in their sustained support for the development of the IPSMP and the guidance provided to the IRRP's Steering and Technical Committees.

The IRRP project would like to thank the management and key officials of the following stakeholder institutions, which include VRA, BPA, GRIDCo, ECG, NEDCo, EPC, PURC, EC, GNPC, and GNGC, for active participation in various activities associated with the development of the IPSMP. The IRRP Steering and Technical Committees (see below) were formed from these agencies, and these members contributed their time generously to ensure that this IPSMP is successfully developed in an inclusive manner. They are also commended for allowing their staff to work closely with the IRRP project, and to provide the necessary data for the IPSMP modelling. All other stakeholders who provided data and specific suggestions that helped to shape the project are also duly acknowledged.

The IPSMP report was based on ICF's planning modelling tool, the Integrated Planning Model (IPM®), for which ICF is 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 they are all gratefully acknowledged.

Ministerial Oversight

Name	Institution	Designation
Hon. John Peter Amewu	Ministry of Energy	Minister of Energy
Hon. William Owuraku Aidoo	Ministry of Energy	Dep. Minister of Energy
Hon. Dr. Amin Adam	Ministry of Energy	Dep. Minister of Energy
Hon. Joseph Cudjoe	Ministry of Energy	Dep. Minister of Energy
Hon. Boakye Agyarko	Ministry of Energy	Former Minister of Energy
Hon. John Jinapor	Ministry of Energy	Former Dep. Minister of Energy/Power

[1] www.icf.com

Name	Institution	Designation
Mr. Lawrence Apaalse	Ministry of Energy	Chief Director
Prof. Thomas Akabzaa	Ministry of Energy	Former Chief Director
Mr. Solomon Asoalla	Ministry of Energy	Former Chief Director

Steering Committee

Name	Institution	Designation	Position
Dr. Nii Darko Asante	Energy Commission	Technical Director	Chairman
Samuel Sarpong*	PURC	Former Executive Secretary	Member
Maame Dufie Ofori	PURC	Executive Secretary	Member
Jabesh Amissah-Arthur*	Bui Power Authority	Former Chief Executive Officer	Member
Fred Oware	Bui Power Authority	Chief Executive Officer	Member
William Amuna*	GRIDCo	Former Chief Executive Officer	Member
Jonathan Amoako-Baah	GRIDCo	Chief Executive Officer	Member
Robert Dwamena*	ECG	Former Managing Director	Member
Samuel Boakye-Appiah	ECG	Managing Director	Member
Frank Akligo	NEDCo	Ag. Managing Director	Member
Kwaku Wiafe	Volta River Authority	Manager	Member
Prof. Thomas Akabzaa*	Ministry of Energy	Former Chief Director	Member
Lawrence Apaalse	Ministry of Energy	Chief Director	Member

Note: * indicates members who were substituted during the course of the project

Technical Committee

Name	Institution	Designation	Position
Dr. Joseph Essandoh-Yeddu	Energy Commission	Director, SPPD	Chairman
Abdul Noor Wahab	VRA	Manager, System Planning	Member
Peter Acheampong	BPA	Manager, Dams Operation	Member
Ben Ahunu	GRIDCo	Principal Engineer	Member
Godfred Mensah	ECG	Manager, System Planning	Member
Mawunyo Rubson	MiDA	Director, Generation Projects	Member
Moses Tawiah	NEDCo	Director, Engineering	Member
Tampuri Tayeeb	NEDCo	Planning Engineer	Member
Nutifafa Fiasorgbor	PURC	Principal Regulatory Engineer	Member
Sulemana Abubakar	MoEn	Deputy Director, Materials	Member
Kwasi Twum-Addo	MoEn	Director, HSSE	Member

ICF Ghana (IRRP Project Team)

Name	Designation
Dr. Ananth Chikkatur	Chief of Party
Maxwell Amoah	Deputy Chief of Party
Bernard Modey	Senior Power Expert
William Sam-Appiah	Project & Programme Development Expert
Maame Tabuah Ankoh	Renewable Energy Specialist
Collins Dadzie	Energy Modeler
Charles Acquaah	M & E Specialist
Edith Mills-Tay	Office Manager
Mawunyo Dzobo	Consultant
Julius Abayateye	Consultant

ICF U.S. Experts

Name	Designation
Juanita Haydel	IRRP Senior Adviser
Maria Scheller	Modelling Expert
Ken Collison	Generation &Transmission Expert
Molly Hellmuth	Climate Change/Resilience Expert

Sub-Consultants (Energy Foundation)

Name	Designation
Ernest Asare	Executive Secretary
Stephen Doudu	Technical Director
Isaac Opoku Manu	Assistant Program Manager

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 the 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). Assumptions used in the modelling are more uncertain in the longer term than in the short-to-medium term. Hence, the need for regular updating of the model.

Five different strategies were developed and each of them was tested against 14 different sensitivities (see ES Figure 1). Specific results or metrics 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 IPSMP

S1 Business as Usual	No technology-specific constraints on build options. Reference assumptions on demand, technology costs, gas resource, renewable energy bounds, total transfer capability, etc.
S2 Indigenous Resources	Utilize indigenous resources as a high-priority; high RE bounds. Build two small hydro plants and a biomass plant. No imports of coal and uranium. Other assumptions are same as BAU.
S3 Diversified Resources	Diversify fuel and resource mix. Build coal, nuclear, biomass, and biogas plants. Other assumptions are same as BAU.
S4 Enhanced G-NDC	Reduce the growth of CO_2 emissions. Constrain CO_2 emissions to half of the BAU Emissions after 2020; high RE bounds. Other assumptions are same as BAU.
S5 Export - Oriented	Increase exports to neighboring countries. Higher export demand, but reference assumptions on domestic and VALCO demand. Other assumptions are same as BAU.

#	Sensitivity
0	Reference
1	High Load Growth
2	Low Load 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
10a, 10b	High Fuel Cost & Limited Water Inflows & High Demand (a) / Low Demand (b)
11	Lower RE Capital Cost & Limited Water Inflows & Higher Fuel Prices
12	Lower Capital Cost for Conventional Resources

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. If disqualified, the next low-cost strategy would be selected for evaluation.

Key Findings from Modelling and Recommendations of the IPSMP

1. **Utilising Ghana's indigenous resources** is both the Least-Regrets strategy and the least-cost option**.** The build plan indicated by this strategy is outlined in ES Figure 2. This build plan will be regularly updated over time to account for changing trends and policy drivers.
   – The average cumulative 10-year investment costs are about $300 million cheaper than the business-as-usual (BAU) strategy.
   – Natural gas is primarily supplied by domestic resources; however, additional gas imports from Nigeria through WAGP and/or regasified imported LNG becomes necessary by mid-2020s, if new domestic resources are not developed by that time.
   – Solar PV and wind costs are expected to decline enough to be built purely on an economic basis by the early 2020s. Solar PV generation in the northern region also reduces transmission losses and mitigates voltage stability issues around Kumasi.
   – Current economics suggests that the wholesale electricity cost is lower when more solar PV and wind capacity is built by 2030 than what was conditionally committed by Ghana in the Paris Climate Agreement. However, if gas prices are significantly lower in the future, then the required variable renewable energy (vRE) capacity decreases.
   – Additional studies, including ancillary services associated with vRE, are needed to fully assess 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, and improve least-cost dispatch of generation.
   – Energy efficiency measures could reduce 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

I. Prioritise the use of indigenous resources (small hydro and other renewables, as well as indigenous natural gas) in power generation.

II. Continue to support development of competitively procured solar PV and wind projects in the range of 20-50 MW, as it could result in lower costs and increase know-how on integration of variable RE plants

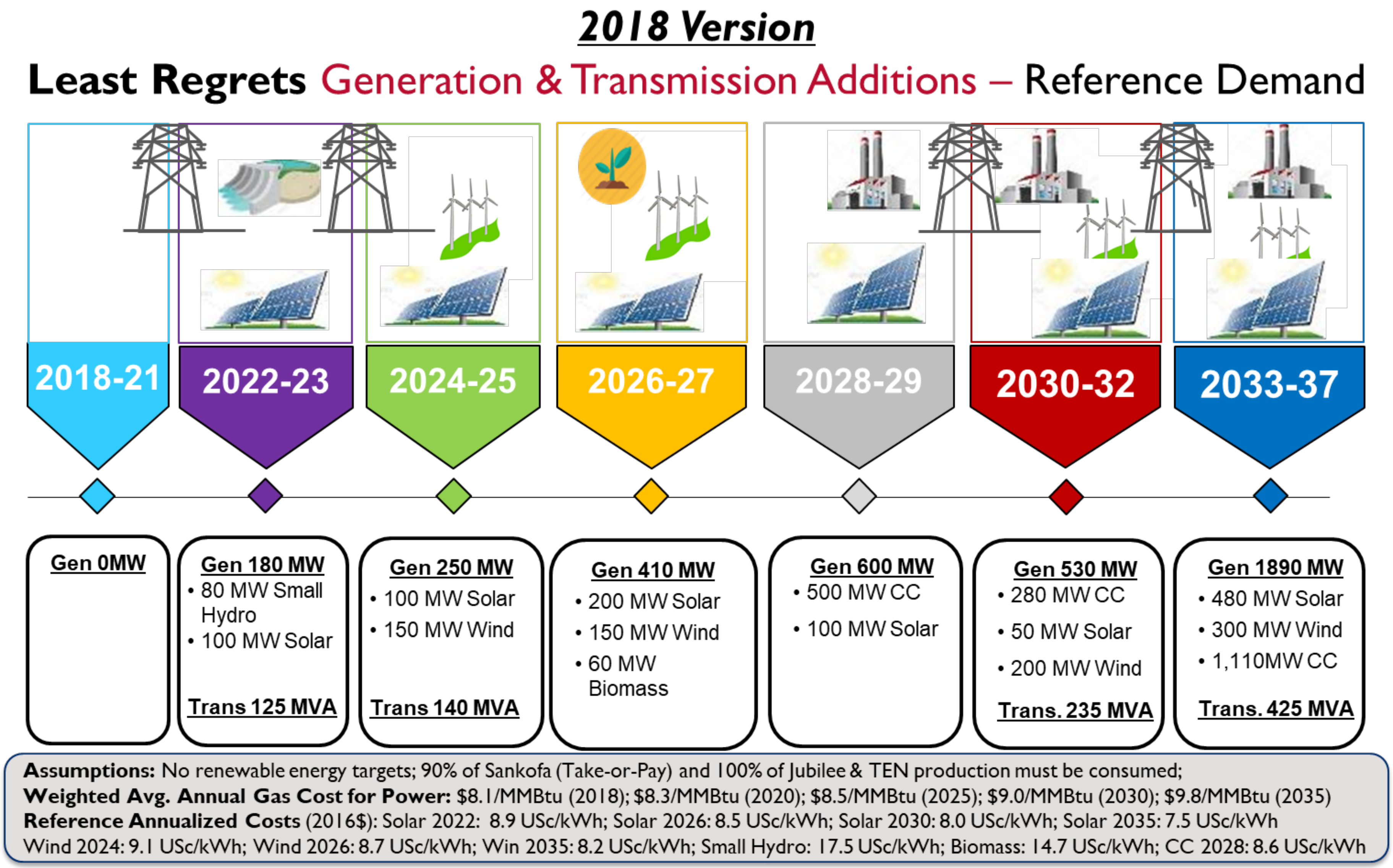
III. Build dispatchable small hydropower plants capable of providing additional non-power benefits (such as irrigation, river transportation, flood control, fisheries, etc.).

IV. As prices decline, consider solar PVs with storage for the middle-to-north of the country, to enhance grid stability.

V. Build biomass plants as part of a Least-Regrets strategy, as they could also provide additional economic benefits and contribute to grid stability.

VI. 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: Least-Regrets Generation and Transmission Additions (Reference Case Demand)



2. There is currently an over-capacity 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 2017, was 3,971 MW; the current recorded peak was 2,496 MW in October 2018.
   - About 700 MW of new capacity (Cenpower, Early Power, and Amandi) is currently under construction, and is expected to come online by the end of 2019, at which time the net-dependable capacity is expected to be above 4,500 MW.
   - The gap between installed capacity and expected Reference Case peak demand, including 20% reserve margin, is more than 1,100 MW from 2019 to 2022. Even under a high-demand scenario, there will be significant excess capacity (see ES Figure 3). The reasons behind the over-capacity situation are explained in detail in the Main Report (Volume 2).
   - 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 could result in lower 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 oil- or gas-based power plants.

Recommendation 2

I. Do not build additional grid-connected conventional plants beyond the ones under construction until the mid-2020s.

II. Timing for new power plants may be influenced by whether TAPCo would be retired or refurbished, and the timeframe for the refurbishment.

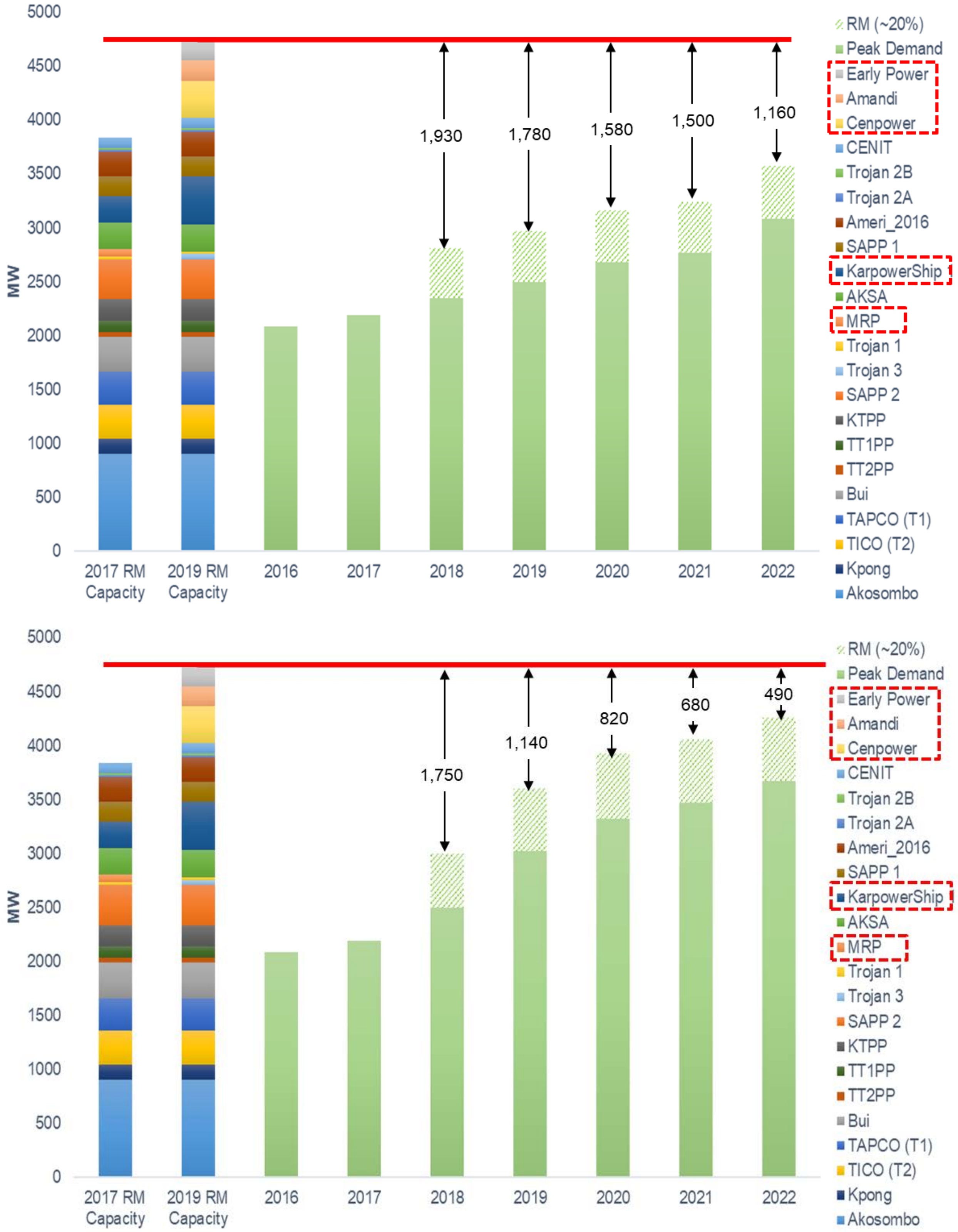
III. Delay implementation of any other conventional plants (e.g., Jacobsen, Rotan) such that they come online by 2025.

IV. Start approvals for procurement and construction for these additional plants in the early 2020s so that plants will be built in time.

V. Implement the wholesale electricity market, as soon as possible, to increase dispatch efficiency and lower generation costs.

VI. Evaluate and implement options to increase natural gas supply reliability for existing and under-construction power plants.

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



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

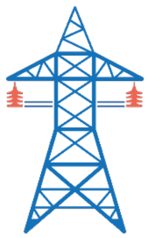
   - From the mid-2020s to early 2030s, 400–1100 MW of thermal capacity is needed, and an additional 500–1300 MW is needed to meet rising demand in the mid-2030s.
   - These thermal capacity needs can be met by either coal and/or gas plants, but these technologies tend to displace each other.
   - Coal 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

I. Assess demand growth, taking into consideration the impact of Energy Efficiency (EE) and demand side management (DSM), for the next IPSMP update (in 2019) to determine the specific timing for new conventional power plants.

II. 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 under current assumptions and economic trends.

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

I. Expedite the construction of the A4BSP substation around Pokuase.

II. Conduct additional transmission analyses to confirm specific transmission builds and improvements in the 2020s, particularly towards the Middle Belt

III. Facilitate the integration of variable REs into the grid in the northern zone through use of modern technologies and operational changes.

IV. Consider building the eastern corridor loop from Kpandu-Kadjebi to Yendi through Juale to increase reliability in the NEDCo zone.

5. Contractual requirements of the Sankofa take-or-pay agreement makes it essential for west-to-east flow of gas (through West Africa Gas Pipeline) to be implemented, mainly because of limitations in the capacity of the plants in the west (i.e., Aboadze power enclave) to fully utilise the available gas in the west.
   - 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, planned increases in gas supply from Greater Jubilee and Nigeria through WAGP could reduce the need for imported LNG for power generation beyond 2023.
   - LNG could be considered as a reliability option for power plants in the Tema enclave; however, take-or-pay LNG contracts could result in additional risks.
   - 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

I. Contract LNG supply to provide gas to power plants in Tema enclave in the short to medium term, based on a comprehensive evaluation of natural gas demand from the power sector, and the availability of reliable supply from Nigerian gas through WAGP, and domestic gas developments.

II. Reconsider liquid fuels contracts for plants in Tema enclave, taking into account potential impact of additional gas supply from Sankofa, WAGP, 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, GNGC, NPI, and other co-opted members as needed. The PPTC should be **jointly chaired** by the Energy Commission and GRIDCo.

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 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 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

I. 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).

II. The MoEn should provide sector policy direction and oversight.

III. The Energy Commission should monitor adherence to formulation, execution, and updates of plans.

IV. 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

I. Location, size, timing, and type of technology or resource for future procurement should all be laid out without creating over-capacity.

II. Competitively procure all future power plants connected to the grid, based on the recommendations of IPSMP and Annual Demand – Supply Plans.

III. Competitively procure new transmission systems based on a Transmission Master Plan that is consistent with IPSMP results.

IV. Bulk and direct customers, who are in the deregulated market, may procure power generation on their own; but need to provide demand forecast and planned procurement information to Energy Commission and PURC

V. Regulated DISCos should seek no-objection from the regulators, Energy Commission, and PURC to proceed with an acceptable competitive procurement process.

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

VII. Expedite implementation of the Ghana Wholesale Electricity Market (WEM) to provide price signals for timing, capacity, and location of new power generation, as well as any required ancillary services.

5 Other Recommendations

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

Demand

a. 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.

b. 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.

c. 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

d. Update the 2011 Transmission System Master Plan, as the model assumptions behind the 2011 study have now changed.

e. 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.

f. 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.

g. Carry out an assessment of the aggregate effect of all vREs (wind & solar) currently connected to the grid, to help in recommending mitigation measures for future variable RE projects.

h. 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

i. Increase the deployment of smart meters and conduct analysis of existing automatic meter reading (AMR) data (particularly boundary meters) to reduce commercial losses.

j. Develop better coordination between the agencies in charge of grid expansion or rural electrification and the distribution companies in connecting new customers to reduce the number of unmetered customers.

k. Limit situations where customers are put on flat rates due to shortage or under-stocking of meters through better inventory management.

l. Use appropriate higher voltages for sub-transmission lines to reduce technical losses. Specifically, modify the Grid Code to enable subtransmission lines to be operated at 69 kV in addition to the existing 33 kV and 11 kV.

m. Extend reliability studies to cover more regional capitals and large towns to improve distribution planning in those towns and cities.

n. Require DISCos to coordinate with GRIDCo on the deployment of solar PVs at the 33kV and 11kV voltage levels from the planning to operation and maintenance stages to reduce grid-integration challenges.

o. 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.

p. Incorporate GIS capabilities into asset management and inventory systems as well as SCADA monitoring to identify overloading on distribution lines and transformers, enhance operations and maintenance of distribution systems, and thereby improve the efficiency and reduce losses of the network.

Regulations

q. 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.

r. All regulatory levies and fees should be transparently determined, and 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.[2] 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.[3]

To assess the potential impacts on the power system, the IRRP project conducted an analysis of these potential changes, and considered the impacts to 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).

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

[2] 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.

[3] 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.

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.[4] 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 'Indigenous Resource' 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 to 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 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, 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.

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

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 first update for the IPSMP by the PPTC is planned for early 2019, with the IRRP project providing the necessary capacity building activities to the PPTC staff in 2018 and 2019, to allow for the PPTC staff to lead the process for the 2019 IPSMP update.

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