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# Integrated Power System Master Plan for Ghana

## Volume #3
Appendices

**December 20, 2018**

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# Volume 3: Appendices for Integrated Power Sector Master Plan

## A. Introduction

This volume contains several analytical reports that summarises the work done by the Integrated Resource and Resilience Planning (IRRP) Project from May 2016 to December 2018. These analytical reports form the basis for the Integrated Power Sector Master Plan (IPSMP) that was described in Volume 1 and Volume 2. This ***Volume 3*** contains the relevant data used and analysis conducted for the development of the IPSMP in a stand-alone set of appendices.

The IRRP Project is being implemented by the U.S. consulting firm, ICF,[1] and funded by the United States Agency for International Development (USAID).

[1] See: www.icf.com.

# B. MONITORING AND EVALUATION PLAN FOR IPSMP IMPLEMENTATION

This section provides a list of activities and events serves as elements of an M&E plan for the IPSMP implementation. The timelines provided below are tentative, and are subject to change. It is expected the Ministry of Energy, the Energy Commission, and the Power Planning Technical Committee (PPTC) would use this plan to assess the implementation status of the IPSMP.

# Matrix for Monitoring and Evaluation

## Focal Area: Power Planning

**Objective:** Manage a comprehensive plan that meets the needs of all mandated planning Agencies, with inputs from all key stakeholders

| No. | Strategic Action | Agency/Department responsible | Tentative Timelines | Verifiable Indicator | Frequency |
|---|---|---|---|---|---|
| 1 | Launching of the IPSMP and inauguration of Power Planning Technical Committee | MoEn/EC/IRRP | 3rd week of January 2019 | IPSMP report launched and published on MoEn/EC/GRIDCo websites<br>PPTC inaugurated | Once |
| 2 | Hold 3 public dissemination fora/seminars in Accra, Kumasi/Tamale and Takoradi on the IPSMP report | MoEn/EC/IRRP team | February 2019 | 3 Public dissemination seminars on IPSMP held at three different locations | 3 times |
| 3 | Hold the first meeting of the PPTC<br>• Discuss the implementation of the PPTC's mandate;<br>• Develop a timetable for PPTC's activities;<br>• Develop a format/agenda to guide PPTC meetings<br>• Present updates to IPSMP modeling<br>• Develop data collection templates and data collection cycles<br>• Develop Ghana IPM training schedule | MoEn (EC/GRIDCO) | February 2019 | Convene the Power Planning Technical Committee and hold the first meeting (3rd week of January)<br>• Mandate discussed<br>• Format for meeting agenda developed<br>• Updates to the IPSMP modelling discussed<br>• Templates developed<br>• Data collection cycles developed;<br>• Ghana IPM training schedule discussed | Once |
| 4 | Hold Power Planning Technical Committee (PPTC) 2nd meeting – March 2019 | PPTC/GRIDCo/EC/IRRP Project | March 2019 | PPTC meeting held (***March 2019***)<br>Minutes of meeting to reflect:<br>• Data collection Templates finalised<br>• Data collection cycles finalised;<br>• Finalise updated modelling inputs Ghana IPM training schedule finalised | Once |

| No. | Strategic Action | Agency/Department responsible | Tentative Timelines | Verifiable Indicator | Frequency |
|---|---|---|---|---|---|
| 5 | Initiate first data collection cycle using data templates | PPTC/EC/GRIDCo | Feb – May 2019 | Survey instruments sent out and data collected | Once a year |
| 6 | Hold fourth Ghana IPM training for PPTC members preceded by discussions on the challenges encountered using data collection templates and possible review of the templates. | IRRP/EC | February 2019 | Fourth Ghana IPM training for members of PPTC held, challenges encountered using data collection templates assessed and reviewed | Every 2-3 months |
| 15 | Analyse and validate IPSMP input data collected using survey templates | PPTC/GRIDCo/EC/IRRP | July – September 2019 | Data collected and validated | September-November each year |
| 7 | Develop updates to the Ghana IPSMP input data | EC/GRIDCo/IRRP | March 2019<br>July 2019<br>November 2019 | Data for updating Annual Supply-Demand Plan and IPSMP collated and updated | Every four months or 3 times in a year |
| 8 | Update the IPSMP build plan to determining the optimum location, size and timing of capacity additions, including renewable energy resources | PPTC/EC/GRIDCo | April 2019<br>August 2019<br>December 2019 | Report detailing the optimum location, size and timing of capacity additions, including renewable energy resources to be updated and submitted to PPTC for Sept 2018 meeting | Every four months or 3 times in a year |
| 9 | Update Connection Agreement (CA) procedure for consistency with the outcome of the Wholesale Electricity Market (WEM) rules, and carry out studies to define appropriate locations on the grid and on the general levels of RE capacities that could be safely connected to the grid, through grid impact studies of various RE installations | GRIDCo/EC | 3 months after promulgation of the GWEM rules | • Connection Agreement (CA) procedure updated for consistency with the Wholesale Electricity<br>• Market (WEM) rules Report on studies | Once |

| No. | Strategic Action | Agency/Department responsible | Tentative Timelines | Verifiable Indicator | Frequency |
|---|---|---|---|---|---|
| 10 | Provide well-informed forecasts on volumes of indigenous gas supplies that will be available for power generation at different locations | GNPC | February 2019<br>August 2019 | Forecast data on volumes and price of delivered indigenous natural gas made available | Two times a year |
| 11 | Provide information on gas infrastructure and determine delivered gas prices for power plants | GNGC | February 2019<br>August 2019 | Data on gas infrastructure, delivered gas price for power plantsprovided | Two times a year |
| 12 | Hold 3rd Power Planning Technical Committee (PPTC) meeting – May 2018 to:<br>• Review of RE locations for 2019 Annual Supply/Demand plan and updated IPSMP<br>• Review Updated Modelling Inputs and Results<br>• Review gas volume/price/infrastructure updates<br>• Monitoring of IPSMP implementation | PPTC/GRIDCo/EC/IRRP | May 2019 | PPTC meeting held (***May 2019***) | |
| 13 | Develop a monitoring report outlining the progress made in the implementation of the IPSMP | EC | July 2019 | Monitoring report developed | Once a year |
| 14 | PPTC to collate and finalize demand forecast of various entities | GRIDCo, ECG, NEDCo and Enclave Power | November 2019 | Demand Forecast for various entities developed | November each year |
| 16 | Update on Thermal Gen plants and Transmission Network | GRIDCO/PPTC | October 2019 | Data on transmission network and status of thermal generation plants updated and provided to PPTC | October of each year |
| 17 | Update hydrology data & evaluate status/contribution of hydropower plants to total annual generation | VRA/PPTC | November 2019 | Data on hydrology updated and hydropower plants generation evaluated by VRA and BPA and provided to PPTC | November of each year |
| 18 | Develop updates of inputs to the Ghana IPSMP | EC/GRIDCo/PPTC | November 2019 | Data for updating Annual Supply-Demand Plan and IPSMP collated and updated | Every 4 months or 3 times in a year |
| 19 | Provide the PURC with the modeling results of the IPSMP and annual-supply plans, so | EC, GRIDCo | December 2019 | Modelling results provided to PURC to guide tariff setting | Every year |

| No. | Strategic Action | Agency/Department responsible | Tentative Timelines | Verifiable Indicator | Frequency |
|---|---|---|---|---|---|
| | that it can use them as part of its tariff setting process and monitoring | | | | |
| 20 | PURC to provide recommendations to PPTC modeling team on assumptions made in the planning (both for IPSMP and Annual Supply-Demand plans). | PURC | December 2019 | Recommendations on assumptions submitted to EC and GRIDCo, as chair of the PPTC | Every year |
| 21 | Develop Draft of Annual Supply-Demand Plan based on existing tools | EC/GRIDCo/PPTC | December 2020 | Draft Annual Supply-Demand Plan | Every year |
| 22 | Hold Power Planning Technical Committee (PPTC) meeting – January 2020 to<br>• Review 2020 Annual Supply/Demand plan<br>• Review Updated Modelling Inputs and Results<br>• Plan for 2020 IPSMP Update<br>• Monitoring of IPSMP implementation | PPTC/GRIDCo/EC | January 2020 | PPTC meeting held (***January 2020***) | Every January |
| 23 | Finalize and release current year Annual Demand-Supply Plan (on EC and GRIDCo website) | PPTC led by EC/GRIDCo | January 2020 | 2020 Annual Demand-Supply Plan released on EC/GRIDCo website | Once a year |
| 24 | Plan for special studies, sub-committee meetings, model review, and data collection surveys | PPTC | February 2020 | Planned list of studies and surveys | Every year |
| 25 | Update the inputs to the Ghana IPSMP | PPTC/EC/GRIDCo | March 2020 | Input data for updating Annual Supply-Demand Plan and IPSMP collated and updated | Every four months /3 times in a year |
| 26 | Update input the input data to EC's Energy Statistics for previous year | PPTC/EC/GRIDCo | March 2020 | Input data to EC's annual Energy Statistics updated | Every March |
| 27 | Hold Power Planning Technical Committee (PPTC) meeting – April 2020 to<br>• Review updated 2019 data, and updated Q1 2020 data<br>• Review Updated Modelling Inputs and Results<br>• Plan for 2020 IPSMP Update | PPTC/GRIDCo/EC | April 2020 | PPTC meeting held (***April 2020***) | Every April |

| No. | Strategic Action | Agency/Department responsible | Tentative Timelines | Verifiable Indicator | Frequency |
|---|---|---|---|---|---|
| | • Monitoring of IPSMP implementation | | | | |
| 28 | Update of the IPSMP, under the EC leadership | EC/PPTC | May – July 2020 | Draft IPSMP updated | Every 2-3 years |
| 29 | Hold continued Ghana IPM training sessions to support IPSMP update | EC | May – June 2020 | Several one-week training sessions held over 2 months | Every year, assuming there is support from USAID |
| 30 | Hold Power Planning Technical Committee (PPTC) meeting – June 2020<br>• Review updated IPSMP report<br>• Review Updated Modelling Inputs and Results from IPSMP<br>• Monitoring of IPSMP implementation | PPTC/GRIDCo/EC | June 2020 | PPTC meeting held (***June 2020***) | Every June |
| 31 | Hold 1-2 Stakeholder meetings on Updated IPSMP | MoEn/EC | July 2020 | Public seminars on updated IPSMP held | Every time IPSMP is updated |
| 32 | Updated IPSMP report released, with revised recommendations and monitoring plan | PPTC/EC | August 2020 | | Every 2 years from 2020 onwards. |
| 33 | Update the inputs to the Ghana IPSMP | PPTC/EC/GRIDCo | August 2020 | Input data for updating Annual Supply-Demand Plan and IPSMP collated and updated | Every four months /3 times in a year |
| 34 | Provide well-informed forecasts on volumes of indigenous gas that will be available for power generation at different locations | GNPC | September 2020 | Data on volume and price of indigenous gas delivered provided to the PPTC | September each year |
| 35 | Provide information on gas infrastructure and determine delivered gas prices for power plants | GNGC | September 2020 | Data on gas infrastructure, delivered gas price provided to PPTC | September each year |
| 36 | Hold Power Planning Technical Committee (PPTC) meeting – September 2020<br>• Review Updated Modelling Inputs and Results | PPTC/GRIDCo/EC | September 2020 | PPTC meeting held (***September 2020***) | Every September |

| No. | Strategic Action | Agency/Department responsible | Tentative Timelines | Verifiable Indicator | Frequency |
|---|---|---|---|---|---|
| | • Review gas volume/price/infrastructure updates<br>• Monitoring of IPSMP implementation | | | | |
| 37 | Conduct demand forecast of operational areas by various entities | ECG, NEDCo and Enclave Power | October 2020 | Demand Forecast for Operational areas developed | October each year |
| 38 | Collect input data for IPSMP using survey templates | PPTC/GRIDCo/EC | September – November 2020 | Survey instruments sent out and input data collected | September-November each year |
| 39 | Update on Thermal Gen plants and Transmission Network | GRIDCO/PPTC | October 2020 | Transmission network and status of thermal generation plants updated and provided to PPTC | October of each year |
| 40 | Update hydrology data & status/contribution of hydropower plants | VRA/PPTC | November 2020 | Hydrology data updated and hydropower plants contribution to total generation evaluated by VRA provided to PPTC | November of each year |
| 41 | Update input data to the Ghana IPSMP | PPTC/EC/GRIDCo | November 2020 | Input data for updating Annual Supply-Demand Plan and IPSMP collated and updated | November each year |
| 42 | Provide the PURC with the modeling results of the IPSMP and Annual Demand -Supply plan so that it can use as part of its tariff setting process and monitoring | EC, GRIDCo | November 2020 | Modeling results provided to PURC to guide tariff setting | November each year |
| 43 | PURC to provide recommendations to PPTC modeling team on assumptions made in the planning (both for IPSMP and Annual Supply-Demand plans). | PURC | December 2020 | Recommendations on assumptions submitted to EC an GRIDCo, as chair of the PPTC | Every December |
| 44 | Develop Draft of Annual Supply-Demand Plan based on existing tools | EC/GRIDCo/PPTC | December 2020 | Draft | Every December |
| 45 | Hold Power Planning Technical Committee (PPTC) meeting – January 2021<br>• Review 2020 Annual Supply/Demand plan<br>• Review Updated Modelling Inputs and Results | PPTC/GRIDCo/EC | January 2021 | PPTC meeting held (***January 2021***) | Every January |

| No. | Strategic Action | Agency/Department responsible | Tentative Timelines | Verifiable Indicator | Frequency |
|---|---|---|---|---|---|
| | • Plan for 2020 IPSMP Update<br>• Monitoring of IPSMP implementation | | | | |
| 46 | Finalize and release current year Annual Demand-Supply Plan (on EC and GRIDCo website) | PPTC led by EC/GRIDCo | January 2021 | 2021 Annual Demand-Supply Plan released on EC/GRIDCo website | Every January |

# C. RESULTS FROM IPSMP ANALYSIS OF SELECTED STRATEGIES

As part of the IPSMP modelling, five different strategies were selected by the IRRP Steering and Technical Committees. The specific metrics that were used for the analysis were discussed Volume 2, Chapter 7. This section provides the metric results for the five strategies across all of the sensitivities that were evaluated.

### Metrics for 10 Years (2018–2027) for Business-As-Usual Strategy

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 1,394 | 1,394 | 1,394 | 1,394 | 1,394 | 1,394 | 1,394 | 1,394 | 1,489 | 1,216 | 1,489 | 1,489 | 1,216 | 1,326 | **1,384** |
| **Total System Cost** | M USD | 7,511 | 9,617 | 6,499 | 7,862 | 5,856 | 7,902 | 8,250 | 7,578 | 7,571 | 7,441 | 12,075 | 5,471 | 7,793 | 7,490 | **7,780** |
| **Unserved energy** | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **Unserved Peak** | MW | 217 | 1629 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1629 | 213 | 217 | 217 | **418** |
| **Transmission Congestion** | % | 21% | 28% | 20% | 20% | 22% | 23% | 21% | 20% | 21% | 21% | 28% | 16% | 20% | 21% | **22%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 84% | 71% | 89% | 84% | 82% | 76% | 70% | 83% | 84% | 84% | 62% | 91% | 84% | 84% | **80%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 18 | 18 | 18 | 18 |  | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | **18** |
| **Local Reserve** | MW | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | **354** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 59 | 77 | 53 | 59 | 59 | 57 | 71 | 59 | 59 | 59 | 68 | 36 | 59 | 59 | **59** |
| **GHG** | Thousand Tons | 8,247 | 10,545 | 6,570 | 8,247 | 8,257 | 8,865 | 8,907 | 8,330 | 8,247 | 8,247 | 12,116 | 5,371 | 8,247 | 8,247 | **8,460** |
| **Ash Production** | Thousand Tons | 73 | 73 | 0 | 73 | 73 | 73 | 0 | 73 | 73 | 73 | 73 | 73 | 73 | 73 | **63** |
| **Land requirements** | Acres | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | 113,736 | **113,736** |

### Metrics for 20 Years (2018–2037) for Business-As-Usual Strategy

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 2,547 | 4,051 | 1,763 | 2,547 | 2,547 | 2,547 | 2,547 | 2,547 | 2,691 | 2,287 | 10,013 | 2,685 | 2,287 | 2,355 | **3,101** |
| **Total System Cost** | M USD | 12,743 | 17,701 | 9,400 | 13,818 | 10,147 | 13,953 | 13,805 | 13,049 | 12,913 | 12,556 | 21,751 | 8,695 | 13,630 | 12,613 | **13,341** |
| **Unserved energy** | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **Unserved Peak** | MW | 217 | 1629 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1629 | 213 | 217 | 217 | **418** |
| **Transmission Congestion** | % | 24% | 34% | 19% | 24% | 25% | 27% | 24% | 24% | 24% | 24% | 36% | 18% | 24% | 24% | **25%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 67% | 54% | 82% | 67% | 65% | 61% | 58% | 65% | 67% | 67% | 47% | 79% | 67% | 67% | **65%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | **10** |
| **Local Reserve** | MW | 380 | 382 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | **380** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 62 | 73 | 49 | 62 | 62 | 61 | 74 | 65 | 62 | 62 | 50 | 33 | 62 | 62 | **60** |
| **GHG** | Thousand Tons | 12,112 | 17,934 | 6,847 | 12,112 | 12,117 | 13,345 | 11,927 | 12,473 | 12,112 | 12,112 | 9,607 | 6,162 | 12,112 | 12,112 | **11,649** |
| **Ash Production** | Thousand Tons | 305 | 533 | 61 | 305 | 305 | 305 | 176 | 305 | 305 | 305 | 158 | 158 | 305 | 305 | **274** |
| **Land requirements** | Acres | 118,084 | 119,359 | 117,191 | 118,084 | 118,084 | 118,084 | 118,084 | 118,084 | 118,084 | 118,084 | 117,729 | 117,313 | 118,084 | 118,084 | **118,031** |

### Metrics for 10 Years (2018–2027) for Indigenous Strategy

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 967 | 967 | 967 | 967 | 967 | 967 | 967 | 967 | 1,077 | 700 | 1,077 | 1,077 | 700 | 960 | **952** |
| **Total System Cost** | M USD | 7,606 | 9,790 | 5,621 | 8,063 | 5,789 | 8,019 | 7,517 | 7,683 | 7,682 | 7,508 | 12,502 | 5,413 | 7,965 | 7,604 | **7,769** |
| **Unserved energy** | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **Unserved Peak** | MW | 217 | 2205 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 2205 | 213 | 217 | 217 | **501** |
| **Transmission Congestion** | % | 23% | 29% | 17% | 22% | 22% | 22% | 23% | 22% | 23% | 23% | 27% | 17% | 22% | 22% | **22%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 84% | 72% | 99% | 84% | 82% | 76% | 98% | 84% | 84% | 84% | 62% | 94% | 84% | 84% | **84%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | **20** |
| **Local Reserve** | MW | 367 | 367 | 367 | 367 | 367 | 367 | 367 | 367 | 367 | 367 | 367 | 367 | 367 | 367 | **367** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 62 | 81 | 44 | 62 | 62 | 59 | 66 | 62 | 62 | 62 | 70 | 38 | 62 | 62 | **61** |
| **GHG** | Thousand Tons | 7,716 | 10,132 | 5,545 | 7,716 | 7,805 | 8,460 | 8,216 | 7,811 | 7,716 | 7,716 | 11,883 | 4,843 | 7,716 | 7,716 | **7,928** |
| **Ash Production** | Thousand Tons | 3 | 3 | 0 | 3 | 0 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | **2** |
| **Land requirements** | Acres | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | 156,084 | **156,084** |

### Metrics for 20 Years (2018–2037) for Indigenous Strategy

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 1,783 | 2,506 | 1,783 | 1,783 | 1,783 | 1,783 | 1,783 | 1,783 | 1,924 | 1,397 | 9,358 | 2,896 | 1,397 | 1,613 | **2,398** |
| **Total System Cost** | M USD | 12,983 | 18,144 | 8,427 | 14,643 | 9,676 | 14,245 | 12,513 | 13,307 | 13,187 | 12,715 | 22,912 | 8,633 | 14,375 | 12,885 | **13,475** |
| **Unserved energy** | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **Unserved Peak** | MW | 217 | 2205 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 2205 | 213 | 217 | 217 | **501** |
| **Transmission Congestion** | % | 23% | 31% | 17% | 23% | 21% | 22% | 23% | 22% | 23% | 23% | 32% | 18% | 23% | 21% | **23%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 68% | 55% | 91% | 68% | 65% | 62% | 85% | 66% | 68% | 68% | 48% | 84% | 68% | 68% | **69%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | **11** |
| **Local Reserve** | MW | 388 | 393 | 388 | 388 | 388 | 388 | 388 | 388 | 388 | 388 | 388 | 388 | 388 | 388 | **389** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 67 | 76 | 34 | 67 | 68 | 69 | 69 | 70 | 67 | 67 | 54 | 34 | 67 | 67 | **63** |
| **GHG** | Thousand Tons | 9,860 | 14,080 | 5,537 | 9,860 | 10,026 | 11,735 | 10,109 | 10,233 | 9,860 | 9,860 | 9,820 | 4,335 | 9,860 | 9,860 | **9,645** |
| **Ash Production** | Thousand Tons | 6 | 6 | 2 | 6 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | **6** |
| **Land requirements** | Acres | 159,674 | 160,737 | 159,674 | 159,674 | 159,674 | 159,674 | 159,674 | 159,674 | 159,674 | 159,674 | 161,907 | 161,667 | 159,674 | 159,674 | **160,051** |

**Metrics for 10 Years (2018–2027) for Diversified Resource Strategy**

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Investment / Capital Cost | M USD | 1,436 | 1,436 | 1,436 | 1,436 | 1,436 | 1,436 | 1,436 | 1,436 | 1,531 | 1,251 | 1,531 | 1,531 | 1,251 | 1,363 | 1,425 |
| Total System Cost | M USD | 7,624 | 9,736 | 6,512 | 7,941 | 5,978 | 8,001 | 8,291 | 7,687 | 7,690 | 7,546 | 12,099 | 5,595 | 7,862 | 7,602 | 7,869 |
| Unserved energy | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unserved Peak | MW | 217 | 1589 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1589 | 213 | 217 | 217 | 413 |
| Transmission Congestion | % | 19% | 28% | 14% | 20% | 21% | 27% | 16% | 22% | 19% | 19% | 30% | 17% | 20% | 19% | 21% |
| Resource type diversity [Dom vs. Imported] | % GWh | 84% | 72% | 90% | 84% | 82% | 76% | 92% | 84% | 84% | 84% | 63% | 90% | 84% | 84% | 83% |
| Fast Ramp/Variable RE Capacity | Ratio | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Local Reserve | MW | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 | 377 |
| Air Quality (Sox, Nox) | Thousand Tons | 58 | 76 | 52 | 58 | 58 | 56 | 70 | 58 | 58 | 58 | 67 | 35 | 58 | 58 | 58 |
| GHG | Thousand Tons | 8,187 | 10,464 | 6,446 | 8,187 | 8,292 | 8,755 | 8,871 | 8,265 | 8,187 | 8,187 | 11,986 | 5,410 | 8,187 | 8,187 | 8,401 |
| Ash Production | Thousand Tons | 84 | 85 | 3 | 84 | 80 | 85 | 9 | 84 | 84 | 84 | 85 | 80 | 84 | 84 | 72 |
| Land requirements | Acres | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 | 2,545 |

**Metrics for 20 Years (2018–2037) for Diversified Resource Strategy**

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Investment / Capital Cost | M USD | 3,747 | 4,035 | 1,699 | 3,747 | 3,747 | 3,747 | 3,747 | 3,747 | 3,876 | 3,487 | 9,908 | 2,633 | 3,487 | 3,377 | 3,927 |
| Total System Cost | M USD | 13,006 | 17,866 | 9,464 | 13,747 | 10,666 | 14,041 | 14,089 | 13,294 | 13,165 | 12,814 | 21,786 | 8,867 | 13,554 | 12,792 | 13,511 |
| Unserved energy | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unserved Peak | MW | 217 | 1589 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1589 | 213 | 217 | 217 | 413 |
| Transmission Congestion | % | 23% | 32% | 16% | 25% | 23% | 29% | 19% | 24% | 23% | 23% | 41% | 17% | 25% | 23% | 25% |
| Resource type diversity [Dom vs. Imported] | % GWh | 67% | 55% | 83% | 67% | 65% | 61% | 78% | 65% | 67% | 67% | 47% | 78% | 67% | 67% | 67% |
| Fast Ramp/Variable RE Capacity | Ratio | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Local Reserve | MW | 392 | 395 | 392 | 392 | 392 | 392 | 392 | 392 | 392 | 392 | 392 | 383 | 392 | 392 | 392 |
| Air Quality (Sox, Nox) | Thousand Tons | 57 | 72 | 48 | 57 | 58 | 55 | 69 | 59 | 57 | 57 | 50 | 33 | 57 | 57 | 56 |
| GHG | Thousand Tons | 11,164 | 17,941 | 6,819 | 11,164 | 11,276 | 12,001 | 10,993 | 11,499 | 11,164 | 11,164 | 9,652 | 6,260 | 11,164 | 11,164 | 10,959 |
| Ash Production | Thousand Tons | 330 | 552 | 71 | 330 | 325 | 330 | 189 | 330 | 330 | 330 | 177 | 175 | 330 | 330 | 295 |
| Land requirements | Acres | 6,088 | 7,669 | 5,035 | 6,088 | 6,088 | 6,088 | 6,088 | 6,088 | 6,088 | 6,088 | 6,026 | 5,610 | 6,088 | 6,088 | 6,087 |

**Metrics for 10 Years (2018–2027) for Enhanced G-NDC Strategy**

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 1,968 | 1,968 | 1,968 | 1,968 | 1,968 | 1,968 | 1,968 | 1,968 | 2,227 | 1,627 | 2,227 | 2,227 | 1,627 | 1,886 | **1,969** |
| **Total System Cost** | M USD | 7,755 | 9,633 | 6,136 | 8,005 | 6,226 | 8,478 | 7,755 | 7,853 | 7,915 | 7,613 | 11,097 | 5,841 | 7,863 | 7,717 | **7,849** |
| **Unserved energy** | GWh | 0 | 2436 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3234 | 0 | 0 | 0 | **405** |
| **Unserved Peak** | MW | 217 | 1553 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1553 | 213 | 217 | 217 | **407** |
| **Transmission Congestion** | % | 25% | 28% | 18% | 26% | 25% | 26% | 25% | 22% | 25% | 25% | 32% | 22% | 26% | 26% | **25%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 89% | 86% | 99% | 82% | 86% | 81% | 89% | 88% | 89% | 89% | 78% | 95% | 89% | 89% | **88%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | **16** |
| **Local Reserve** | MW | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | 398 | **398** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 53 | 57 | 42 | 53 | 54 | 44 | 53 | 53 | 53 | 53 | 46 | 32 | 53 | 53 | **50** |
| **GHG** | Thousand Tons | 7,241 | 7,530 | 5,527 | 7,241 | 7,251 | 7,144 | 7,241 | 7,241 | 7,241 | 7,241 | 7,642 | 4,616 | 7,241 | 7,241 | **6,974** |
| **Ash Production** | Thousand Tons | 28 | 9 | 0 | 28 | 5 | 9 | 28 | 21 | 28 | 28 | 9 | 19 | 28 | 28 | **19** |
| **Land requirements** | Acres | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | 115,685 | **115,685** |

**Metrics for 20 Years (2018–2037) for Enhanced G-NDC Strategy**

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 3,371 | 5,445 | 2,173 | 3,371 | 3,371 | 3,371 | 3,371 | 3,371 | 3,697 | 2,872 | 9,998 | 3,409 | 2,872 | 3,123 | **3,844** |
| **Total System Cost** | M USD | 13,216 | 18,145 | 8,922 | 14,292 | 10,554 | 15,153 | 13,216 | 13,627 | 13,587 | 12,851 | 21,412 | 9,166 | 13,927 | 13,066 | **13,652** |
| **Unserved energy** | GWh | 0 | 1218 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1617 | 0 | 0 | 0 | **203** |
| **Unserved Peak** | MW | 217 | 1553 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1553 | 213 | 217 | 217 | **407** |
| **Transmission Congestion** | % | 34% | 28% | 20% | 34% | 34% | 35% | 34% | 33% | 34% | 34% | 33% | 24% | 34% | 35% | **32%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 74% | 64% | 91% | 70% | 71% | 68% | 74% | 72% | 74% | 74% | 58% | 87% | 74% | 74% | **73%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 8 | 9 | 9 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 9 | 9 | 8 | 8 | **9** |
| **Local Reserve** | MW | 420 | 420 | 416 | 420 | 420 | 420 | 420 | 420 | 420 | 420 | 416 | 416 | 420 | 420 | **419** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 58 | 58 | 38 | 58 | 60 | 43 | 58 | 62 | 58 | 58 | 40 | 28 | 58 | 58 | **52** |
| **GHG** | Thousand Tons | 8,797 | 10,992 | 5,684 | 8,797 | 8,917 | 9,119 | 8,797 | 9,016 | 8,797 | 8,797 | 7,708 | 4,640 | 8,797 | 8,797 | **8,404** |
| **Ash Production** | Thousand Tons | 52 | 43 | 35 | 52 | 36 | 12 | 52 | 34 | 52 | 52 | 43 | 48 | 52 | 52 | **44** |
| **Land requirements** | Acres | 122,665 | 121,778 | 117,815 | 122,665 | 122,665 | 122,665 | 122,665 | 122,665 | 122,665 | 122,665 | 121,380 | 119,053 | 122,665 | 122,665 | **121,905** |

### Metrics for 10 Years (2018–2027) for Export-Oriented Strategy

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 1,445 | 1,445 | 1,445 | 1,445 | 1,445 | 1,445 | 1,445 | 1,445 | 1,540 | 1,267 | 1,540 | 1,540 | 1,267 | 1,372 | **1,435** |
| **Total System Cost** | M USD | 7,484 | 9,621 | 6,908 | 7,890 | 5,751 | 7,924 | 8,215 | 7,551 | 7,544 | 7,414 | 12,217 | 5,586 | 7,821 | 7,462 | **7,814** |
| **Unserved energy** | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **Unserved Peak** | MW | 217 | 1136 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1136 | 213 | 217 | 217 | **348** |
| **Transmission Congestion** | % | 22% | 26% | 17% | 21% | 22% | 24% | 25% | 21% | 21% | 21% | 29% | 13% | 21% | 22% | **22%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 82% | 70% | 87% | 82% | 80% | 74% | 91% | 82% | 82% | 82% | 61% | 91% | 82% | 82% | **81%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | **18** |
| **Local Reserve** | MW | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | 354 | **354** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 60 | 79 | 54 | 60 | 60 | 58 | 73 | 61 | 60 | 60 | 69 | 34 | 60 | 60 | **61** |
| **GHG** | Thousand Tons | 8,506 | 10,852 | 6,753 | 8,506 | 8,522 | 9,216 | 9,144 | 8,589 | 8,506 | 8,506 | 12,489 | 5,068 | 8,506 | 8,506 | **8,690** |
| **Ash Production** | Thousand Tons | 78 | 78 | 0 | 78 | 78 | 78 | 4 | 78 | 78 | 78 | 78 | 62 | 78 | 78 | **66** |
| **Land requirements** | Acres | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | 113,756 | **113,756** |

### Metrics for 20 Years (2018–2037) for Export-Oriented Strategy

| METRIC | Unit | RefCase | High Demand | Low Demand | High Fuel Cost | Low Fuel Cost | Limited Fuel Supply | High Fuel Supply | Limited Water Availability | Higher RE Capital Costs | Lower RE Capital Costs | High Demand, High Resource Cost, low fuel/water availability | Low Demand, High Resource Cost, low fuel/water availability | Lower RE capital costs and higher fuel Costs | Lower Capital Cost for Conventional Resources | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Investment / Capital Cost** | M USD | 2,677 | 4,166 | 1,833 | 2,677 | 2,677 | 2,677 | 2,677 | 2,677 | 2,821 | 2,417 | 10,459 | 2,510 | 2,417 | 2,463 | **3,225** |
| **Total System Cost** | M USD | 12,794 | 17,851 | 10,094 | 13,982 | 10,085 | 14,002 | 13,779 | 13,113 | 12,871 | 12,514 | 21,920 | 8,867 | 13,794 | 12,650 | **13,451** |
| **Unserved energy** | GWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **Unserved Peak** | MW | 217 | 1136 | 213 | 217 | 217 | 217 | 217 | 217 | 217 | 217 | 1136 | 213 | 217 | 217 | **348** |
| **Transmission Congestion** | % | 25% | 32% | 17% | 25% | 26% | 26% | 27% | 24% | 24% | 24% | 36% | 15% | 25% | 25% | **25%** |
| **Resource type diversity [Dom vs. Imported]** | % GWh | 65% | 53% | 82% | 65% | 64% | 59% | 78% | 63% | 65% | 65% | 46% | 80% | 65% | 65% | **66%** |
| **Fast Ramp/Variable RE Capacity** | Ratio | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | **10** |
| **Local Reserve** | MW | 380 | 382 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | **380** |
| **Air Quality (Sox, Nox)** | Thousand Tons | 64 | 74 | 48 | 64 | 64 | 63 | 75 | 66 | 64 | 64 | 51 | 31 | 64 | 64 | **61** |
| **GHG** | Thousand Tons | 12,642 | 18,400 | 6,869 | 12,642 | 12,650 | 13,976 | 12,471 | 13,002 | 12,642 | 12,642 | 9,895 | 5,952 | 12,642 | 12,642 | **12,076** |
| **Ash Production** | Thousand Tons | 326 | 543 | 65 | 326 | 326 | 326 | 198 | 326 | 326 | 326 | 168 | 161 | 326 | 326 | **291** |
| **Land requirements** | Acres | 118,162 | 119,417 | 117,591 | 118,162 | 118,162 | 118,162 | 118,162 | 118,162 | 118,162 | 118,162 | 117,773 | 117,298 | 118,162 | 118,162 | **118,121** |

# D. DEMAND ANALYSIS REPORT

Starting in May 2016, the IRRP project collected previous reports that had developed forecast for electricity demand. This attached report describes the state of demand analysis as of April 2017. Additional analysis has been done since then, which has been reflected in Volume 2.

# Integrated Resource and Resilience Planning (IRRP) Project

## Review of Ghana Electricity Demand Forecast and IRRP Demand Estimates

April 2017

# Contents

## DISCLAIMER:

# 1. BRIEF BACKGROUND

Ghana has a long history of long term planning in the power sector which dates back to the early 1970's. Prior to the unbundling of the power sector, the Volta River Authority (VRA) was responsible for long-term planning for the power sector. Following the creation of Energy Commission (EC) as part of the power sector reforms however, long-term energy planning in Ghana became the responsibility of the EC. The first long-term energy plan called the Strategic National Energy Plan (SNEP), which covered 2006 to 2020, was initiated by the EC in 2000 and published in 2006. The update of the SNEP is currently ongoing and will cover the forecast period 2016 to 2035.

A key element of such power planning is the development of long term peak load and energy forecasts in Ghana which have been undertaken by Ghana's power sector utilities and the EC, often in partnership with external consultants. These demand forecasts have been aimed at meeting their respective institutional needs. As part of this process, long-term load forecast reports are published by the utilities which usually covers a period of about ten (10) years. These load forecast reports are usually updated annually to revise and update the underlining assumptions used.

In this paper, the Integrated Resource and Resilience Planning (IRRP) Team, supported by USAID/Ghana, has reviewed a number of recent load forecast reports in order to evaluate the potential for their use for the Integrated Power Sector Master Plan (IPSMP). The IPSMP needs a consensus-based reference demand forecast, which should consider the potential for demand side management, energy efficiency, and climate changes. This review analysis is a first step in such a process.

The IRRP team collected and reviewed the current load forecast reports of the various Ghana power agencies in order to assess their adequacy for the IPSMP. The rationale for the exercise was to learn what has been done already and evaluate what more needs to be done. Specifically, the review of the existing reports sought to:

- understand the methodologies and assumptions used;
- identify commonalities and differences;
- understand the benefits and challenges associated with each model;
- understand the geographic distribution of growth; and
- develop a reference case demand forecast.

The review process was guided through interactions with key technical staff of the various utilities as well as the IRRP Steering and Technical Committees. In some cases however, the IRRP Team had to rely on its interpretation of existing reports only.

In developing the reference case demand forecast, the IRRP team developed an econometric methodology for the IPSMP to forecast peak and energy demand for Electricity Company of Ghana (ECG) and Northern Electricity Distribution Company (NEDCo) based on the review of the forecast reports. The methodology developed uses a log-log linear regression with GDP as the only independent variable in the regression analysis so as to ensure consistency for both ECG and NEDCo. For bulk customers', the 2014 GRIDCo Supply Plan together with some updates from GRIDCo formed the basis for their demand projections. The IRRP Team in consultation with the IRRP Technical Committee also agreed on a reference forecast for VALCO. Details of the IRRP demand forecast is presented in Section 3.

# 2. COMPARISON OF LOAD FORECASTS

An understanding of how electricity demand is forecasted by different institutions is critical to the development of the reference case forecast. The IRRP Team received forecast reports from the VRA, GRIDCo, ECG and NEDCo. Additionally, the EC also furnished the Team with a copy of its draft SNEP II report. Accordingly, the IRRP team's review of the SNEP II report is based on the draft report. A recent study conducted by Nexant for USAID was also received. In all, seven forecast reports were reviewed. A list of the forecast reports received and reviewed is shown in Table 1.

Table 1: Load forecast reports reviewed

| No. | Institution | Report | Year of Publication | Forecast Period |
|---|---|---|---|---|
| 1 | Volta River Authority | Load Forecast, Final Report | October 2014 | 2015 to 2030 |
| 2 | Ghana Grid Company | Generation Master Plan Study For Ghana | November 2011 | 2011 to 2026 |
| 3 | Ghana Grid Company | Transmission System Master Plan For Ghana | February 2011 | 2010 to 2020 |
| 4 | Electricity Company of Ghana Limited | 2015 Energy and Demand Forecast Review; Ten Year Energy Forecast | October 2015 | 2015 to 2024 |
| 5 | Northern Electricity Distribution Company | Long-Term Load Forecast | April 2015 | 2015 to 2024 |
| 6 | Energy Commission | [Draft] Strategic National Energy Plan (SNEP II); Energy Demand Projections for Ghana; Final Draft II | To be Published | 2015 to 2035 |
| 7 | USAID/Nexant | Electricity Demand Forecasting and Suppressed Demand Estimation Study | April 2016 | 2015 to 2030 |

The purpose and scope of each of the forecast reports is contingent on the respective goals of the institution. For instance, whereas the forecast reports of the distribution companies (ECG and NEDCo) focus only on their operational areas, the reports from VRA, GRIDCo, EC and USAID/Nexant covers the entire country. The Appendix presents a detailed overview of the input data, methodology and assumptions used by the various agencies.

A review of the reports showed that the power utilities adopted a top-down econometric approach to forecast demand. They develop an econometric model by estimating the forecasting parameters with historical data. The model is then used to develop projections using growth assumptions of the independent variables. Regarding the use of historical electricity consumption data in estimating regression models, it is important to note that measured consumption data, thus far, does not reflect full demand for electricity in Ghana. First, the existence of constraints in the system prevents consumption from reflecting true demand. Subject to integrity issues, available data in Ghana at present include:

- Gross electricity generated metered at the power generators
- Net electricity generated metered by GRIDCo at power plants
- Grid-based electricity delivered metered by GRIDCo at the BSPs
- Electricity purchases computed by ECG/NEDCo/GRIDCo based on metered data at BSPs on utility side
- Electricity sales estimated by ECG/NEDCo/GRIDCo based on metered data at customer sites
- Estimated Distribution losses: (Purchases-Sales)/Purchases
- Estimated Transmission loss: (Net Generated – Delivered)/Net Generated
- Imports and Exports reported by GRIDCo and WAPP

Therefore, not all electricity consumption is being measured and/or collected, due to self-generation, power theft, non-metering, meter malfunctions. Price sensitivity of sales and data collection problems, among others, cannot be overstated. The need to estimate the "true demand" for Ghana therefore, is very critical for any planning purpose. Nexant conducted an initial analysis regarding suppressed demand (see below); however further analysis is required to better reflect the true suppressed demand.

Unlike the utilities, the EC uses a different methodology; they employ a bottom-up approach using the Long-Range Energy Alternatives Planning (LEAP) model to estimate energy demand. Input data used for the LEAP modelling include information on end users, technologies and consumption patterns which are obtained from surveys on customer electricity consuming equipment and operations. Further, forecasts are made projecting equipment quantity, energy use per device and expected intensity and time of use. Although the LEAP model, like any other model has its limitations, results from LEAP model could be used to:

- assess suppressed demand in the short-term;
- evaluate how specific policies policies that impact demand forecasts (e.g., time-of-use tariffs, energy efficiency goals, demand side management supported by smart meters)
- develop in-depth understanding of the output of a different model by comparing LEAP's optimization functionality to other models

As noted earlier, apart from the EC forecast, all the other forecasts used linear regression analysis to forecast demand. Generally, all the regression models used different combinations of three main explanatory variables: GDP, Population and Retail Price. The basis for determining the independent explanatory variables were usually correlation analysis that picked the variable with the highest R-square with the dependent variable - electricity consumption. This approach, however, is likely to result in the use of highly collated explanatory variables. Even though, the model may have high R-square, it is not good to use correlated variables.

For instance, GRIDCo's Generation Master Plan used previous year's GDP, population, and current year GDP per capita in their regression model. However, GDP and population are highly correlated. Similarly, ECG used customer population, price, and current-year GDP to forecast its load. Customer population and GDP could be correlated as well. Table 2 summarizes the key assumptions used in all of the reviewed reports.

Table 2: Summary of key assumptions

| Report | Variables Used | | |
|---|---|---|---|
| | **GDP** | **Population** | **Price** |
| VRA | •GDP forecasts from IMF Report (in USD at 2006 constant prices)<br>•ECG and NEDCO sales regressed on GDP<br>•Forecast ends in 2019. Moving average used to extrapolate from 2020 to 2030 based on 2013 to 2019 | Not used | Not used |
| Generation Master Plan | • Domestic consumption regressed on GDP and GDP per capita<br>• GDP forecasts from IMF from 2011 to 2015.<br>• Rate of 5.8% used for 2016 to 2026 based on trend between 2010 to 2015<br>• Economic parameters expressed in GHS at 2000 constant prices | Population forecasts from IMF from 2011 to 2015; trend from 2010 to 2015 used to forecast for the remaining period | Not used |
| Transmission Master Plan | • GDP forecasts from 2010 to 2014 was obtained from IMF.<br>• Rate of 6.1% used for 2014 to 2020 based on trend between 2010 to 2014<br>• Real GDP growth rates in constant GHS prices | Not used | Not used |
| ECG | • Total GDP in 2006 constant GHS was used for NSLT whiles Non-Agric GDP was used for SLT<br>• Growth rate assumptions beyond IMF projections was based on a trending method | Population figures for NSLT and SLT was used<br>Basis for growth rate assumptions stated in report | Real average NSLT prices was used for NSLT model |
| NEDCo | • Real GDP per capita growth rates used for 2015 to 2019 (in constant 2006 GHS) was based on IMF Country Data 2014 report.<br>• That of year 2020 onwards was estimated at 4.7% | 6.5% growth rate was used based on historical trend | Rate of 7% was used to forecast price |
| USAID/Nexant | • Assumed base case growth rates based on IMF and World Bank projections. | Variables included Ghana pop, average household size, residential customers, non-residential customers, SLT Customers<br><br>Growth rates assumptions based on historical trend | • Used average end-use price from EC Report<br>• Assumed base case growth rates based on historical trend |

Source: ICF analysis of existing load forecast reports in Ghana

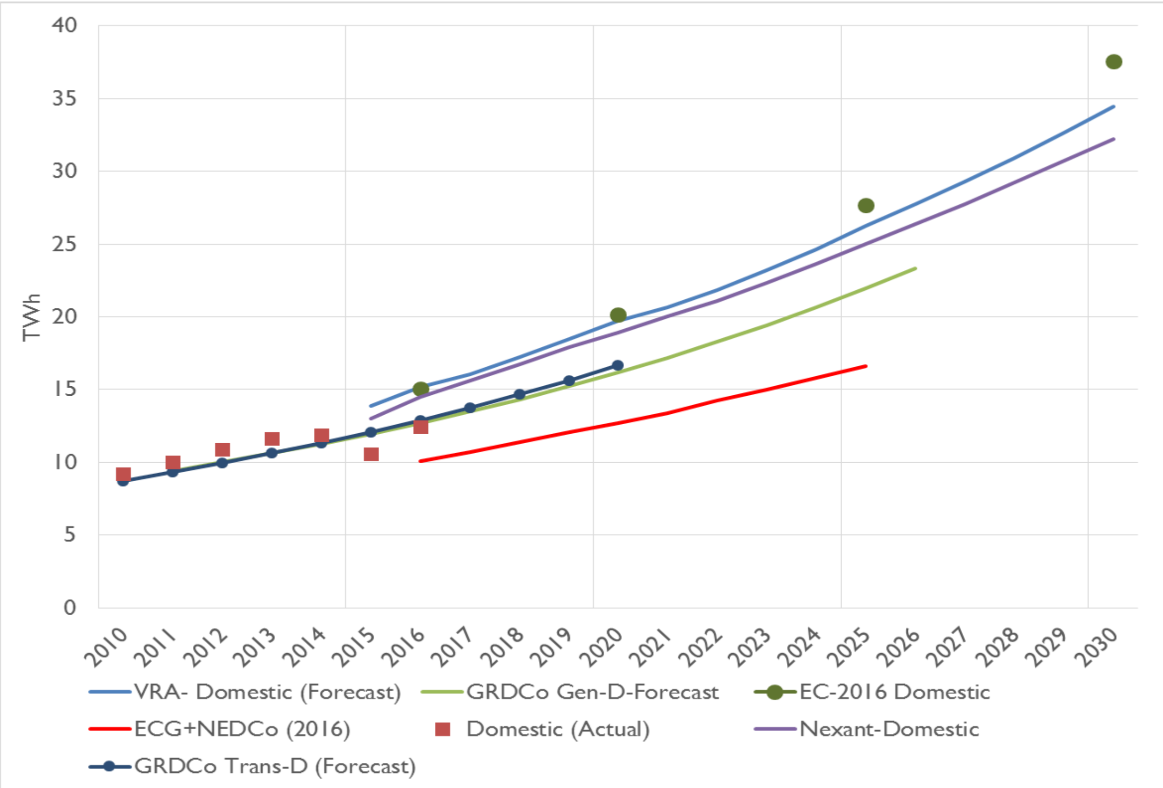
Typically, three different scenarios – high, base and low case scenarios – were modelled by all institutions with the exception of the EC forecast. The EC developed two scenarios called the Business-As-Usual (BaU) and Accelerated Economic Growth (AEG) – which compares with the base case and high case scenarios respectively. For the purpose of this report however, only the base case or BaU scenarios were compared.

The forecasting time horizon for the load forecasts vary from one institution to the other as shown in Table 1. The comparison was therefore done over the entire forecast period which spans from 2010 to 2030.

Figure 1 presents a comparison of the base case energy forecast. The comparison was done for domestic electricity consumption which refers to total electricity consumption in Ghana (as measured by various utilities) minus the electricity consumption of the Volta Aluminium Company (VALCO) and net exports primarily due to the unique behaviour of their demand. Data was also collected on actual domestic consumption from 2010 to 2016 and included in the comparison.

To reiterate the purpose of the comparison, the IRRP Team sought to understand the methodologies and assumptions used, identify commonalities and differences, and also better understand the benefits and challenges associated with each forecast. This is in line with the process of developing a reference cast forecast.

Figure 1: Energy demand forecasts comparison




Source: Existing Load Forecast Reports

Within the forecasting time horizon being compared, the EC SNEP II report provided projections for some years (2016, 2020, 2025, 2030) only. All the other forecasts however gave year-on-year projections. Given that ECG and NEDCo forecasts only concentrate on their operational areas, forecasts by VRA, GRIDCo, EC, and Nexant can be compared the best.

Generally, all the forecasts trend upwards, following a similar trajectory. The most optimistic demand growth is the forecast by EC primarily due to its demand forecast methodology, as well as the non-consideration of potential constraints (supply, network, price impacts, etc.) in the power system. Therefore, the EC forecast can be considered as a theoretical, indicative forecast.

As shown above, the VRA forecast is about the same as the Energy Commission forecast from 2016 to 2020. From 2021 onwards, the EC forecast moves higher than that of VRA. GRIDCo's Generation Master Plan forecast follows about the same trend as that of the USAID/Nexant forecast from 2017 to 2026. Of interest though is the Generation Master Plan forecast which seems slightly lower than that the Transmission Master Plan though the latter study was undertaken first.

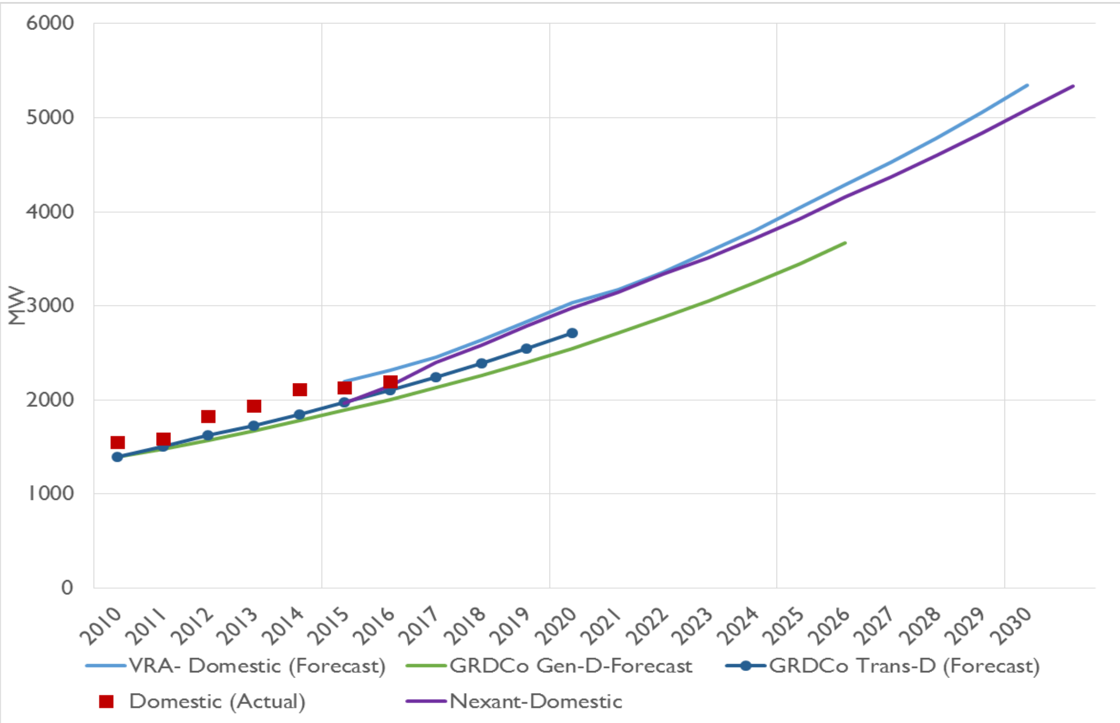



Figure 2: Peak demand forecasts comparison
Source: Existing Load Forecast Reports

Peak demand forecasts followed the same trend as that of the energy demand forecasts. This can be attributed to how peak demand projections are estimated. To estimate peak demand projections, energy demand forecast are converted to peak forecast using load factors. The draft SNEP II report however does not provide data on peak demand estimates. Details of the load factors used in the reports are shown in the Appendix.

Most of the differences in load forecast among the institutions can be explained by the different regression methodologies and GDP growth rate assumptions used. Although the GDP forecasts used by the various institutions were sourced from the International Monetary Fund (IMF), they were sourced from IMF publications at different times, and more importantly, they were used differently by each institution. For instance, whereas GRIDCo's Generation Master Plan used previous year's GDP (GDP-1), the GRIDCo Transmission Master Plan used only current-year GDP. Similarly, whereas ECG used current year's GDP to forecast its load, VRA in determining ECG's demand in VRA's forecast used the GDP from the previous two years (GDP-2)[1]. The IMF GDP growth forecasts for Ghana is a short-term forecast; hence, most of the forecast reports used a moving average based on the IMF forecast to forecast the remaining years in their respective forecast periods. A comparison of the GDP growth rate assumptions used in the load forecast reports is shown in Figure 3.

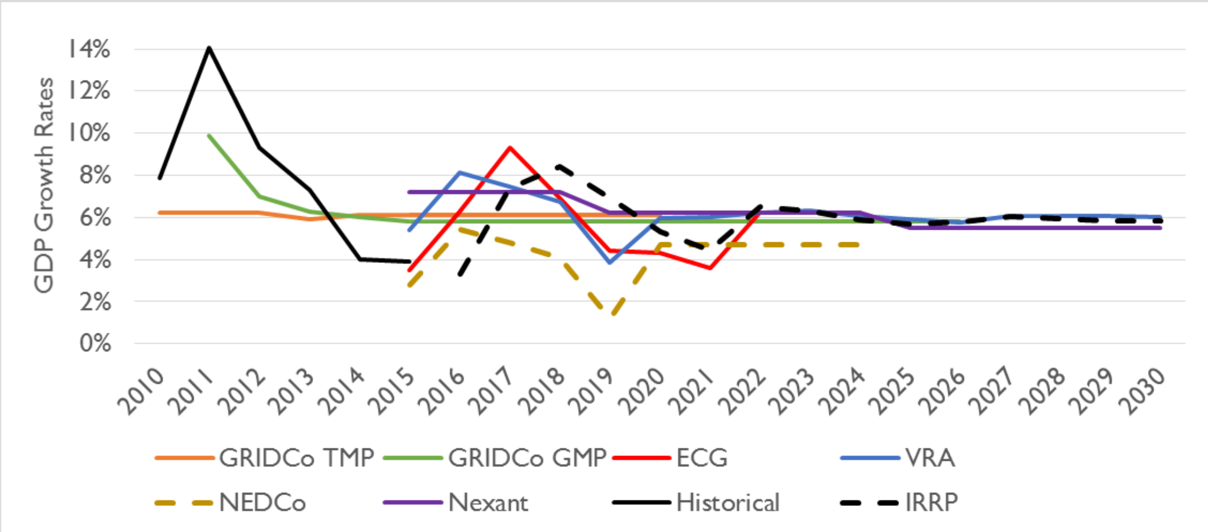



Figure 3: Comparison of GDP Growth Rates
Source: Existing Load Forecast Reports and GSS

As depicted above, actual GDP growth varied greatly with the forecasts from 2010 to 2015. Forecasts for VRA, IRRP, and Nexant however seem to follow a similar trajectory from 2022 onwards. The IRRP GDP growth rates used here are based on the September 2016 IMF Ghana Country Data report. The IMF report provides GDP forecasts to year 2021. A 5-year moving average was therefore used to extrapolate the forecast to year 2030. The section next section provides details of the IRRP project's Demand Estimates that can be used for the IPSMP.

## 3. INITIAL REFERENCE CASE IRRP DEMAND ESTIMATES

Ultimately, the goal of the IRRP project is to adopt and refine existing forecasts to build consensus around an updated reference forecast and alternative demand scenarios for the IPSMP modelling. The IPSMP demand forecasts will be reviewed and approved by the Steering and Technical Committees. While the EC forecast for electricity demand in the SNEP report is currently considered as the country's reference case, there are a number of potential ways

[1] Note also that the historical GDP data used in these reports sometimes had different base-years and currencies. For instance, whereas VRA's GDP data was in constant 2006 USD, that of the Generation Master Plan was in constant 2000 GHS.

in which both the econometric and bottom-up LEAP modeling can be aligned. For instance, results from the LEAP model can aid in assessing suppressed demand in the short-term.

To develop an updated reference case energy and demand forecast for the Ghana IPM model, the IRRP team developed forecasts for ECG, NEDCo, Bulk Customers, VALCO and Transmission Losses. To forecast ECG demand, a log-log linear regression of ECG sales was done using GDP as the only independent variable. GDP projections was obtained from the September 2016 IMF Ghana country report as mentioned earlier. In conducting the analysis, one-half of the measured losses was assumed to be potential sales. Total distribution losses was also assumed to decrease from about 23% in recent years to about 12% by 2030. Over this same period, technical losses was assumed to decrease from 11.5% to 7%. ECG sales was then converted to purchases based on the loss factor.

After the regression analysis was performed and forecasts for ECG was obtained, the total energy demand was split among Ashanti, South East and South West regions based on the ratios for these model regions from the ECG 2016 demand projections.
Similar to ECG, a log-log linear regression of NEDCo sales was done using GDP as the only independent variable for IRRPs forecast for NEDCo. This ensures consistency of both methodology and assumption between the two forecasts. For NEDCo however, total distribution system losses was assumed to decrease from 21% in recent years to 13% by 2030.

Demand projections for Bulk Customers were estimated for each zone based on the GRIDCo 2014 Supply Plan with additional updates from GRIDCo. In estimating the demand for bulk customers, only BCs connected to the transmission system were taken into account as ECG's bulk customers are already included in the demand projections. Finally, to account for transmission losses within each zone, a forecast was done based on outputs of PSSE analysis. Transmission losses were then treated as demand and added to the demand for each zone. The Appendix provides details of the IRRP peak demand and energy forecast for ECG and NEDCo. Figure 4 shows a comparison of IRRPs energy demand forecast with the reviewed forecasts and actual demand.

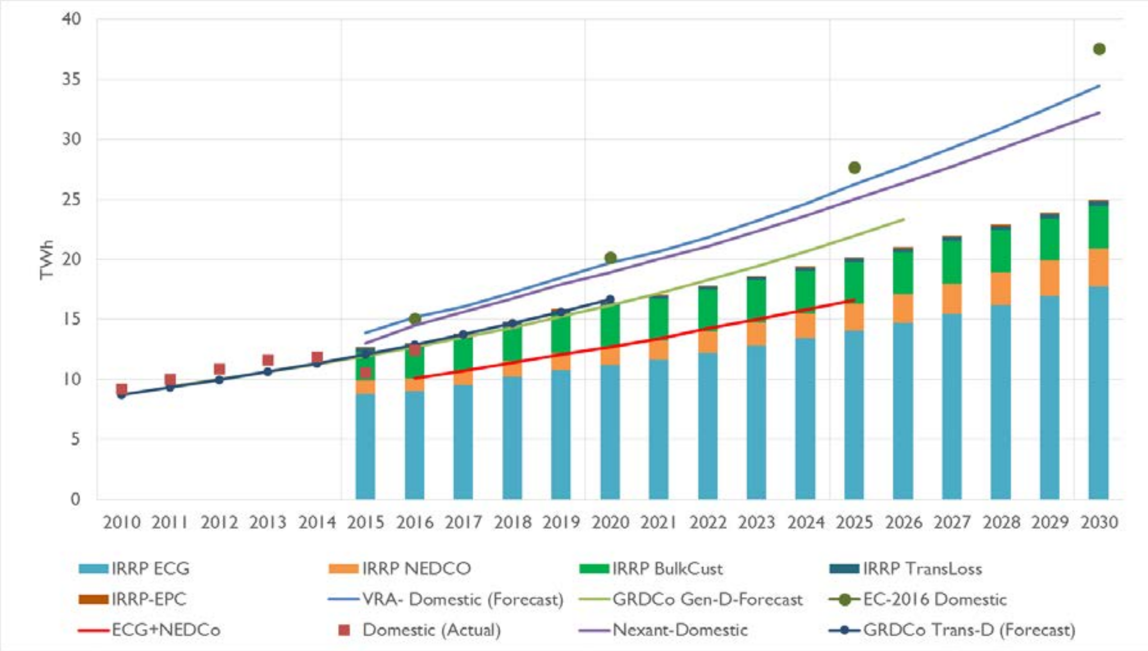



Figure 4: Comparison of Energy Demand Forecasts
Source: IRRP Analysis

Similar to the reviewed load forecasts where energy demand projections were converted to peak forecasts using load factors, the IRRP team estimated peak forecasts based on the energy forecasts using load factors. Below is a comparison of the IRRP projected peak demand forecasts with previous forecasts and actual peak demand.

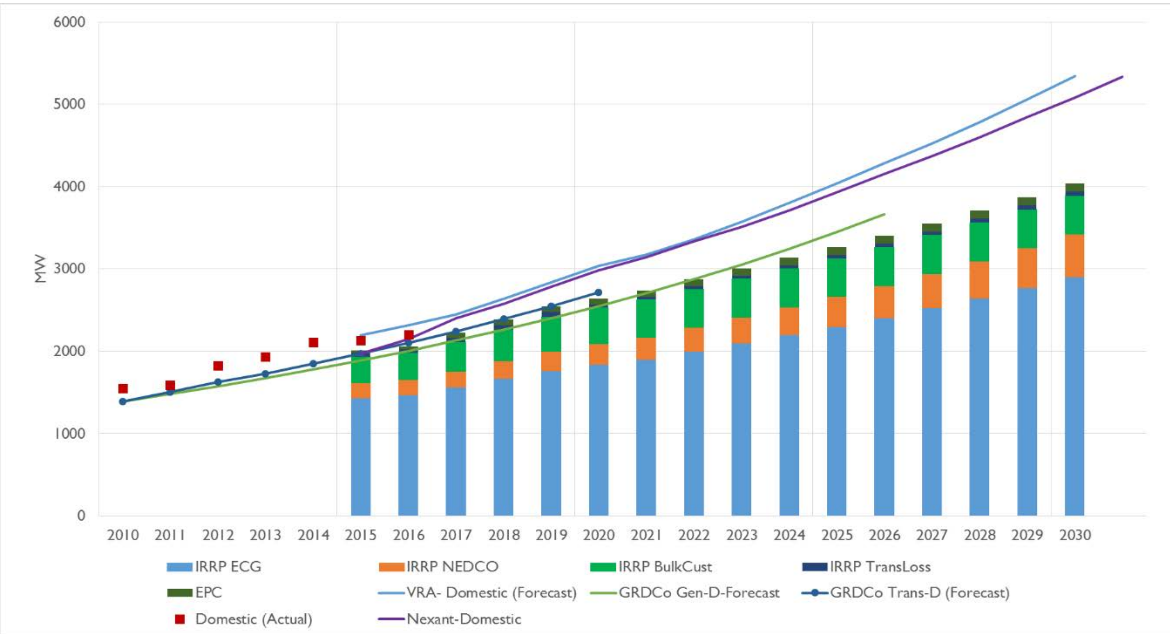



Figure 5: Comparison of Peak Demand Forecasts
Source: IRRP Analysis

# 4. VALCO AND NET EXPORTS

## 4.1 VALCO

Forecasting electricity demand from VALCO has been particularly challenging, in recent years. While VALCO was a key contributor to Ghana's exports in the past, it is now a much smaller contributor to the economy, as Ghana's industrial base has become more diverse. As shown in Figure 6, VALCO's share of energy consumption to total energy consumption was very significant in the 1990's. Currently, even if VALCO operated all 6 potlines at full capacity, it will only account for about 12% of overall electricity consumption in Ghana.

The IRRP team conducted some analysis to find out how the total electricity consumption in Ghana, inclusive of VALCO, correlates with Ghana's total GDP. The graph below presents historical (1990 to 2014) electricity consumption for Ghana without VALCO, total electricity consumption for Ghana with VALCO and GDP in 2006 constant USD prices.

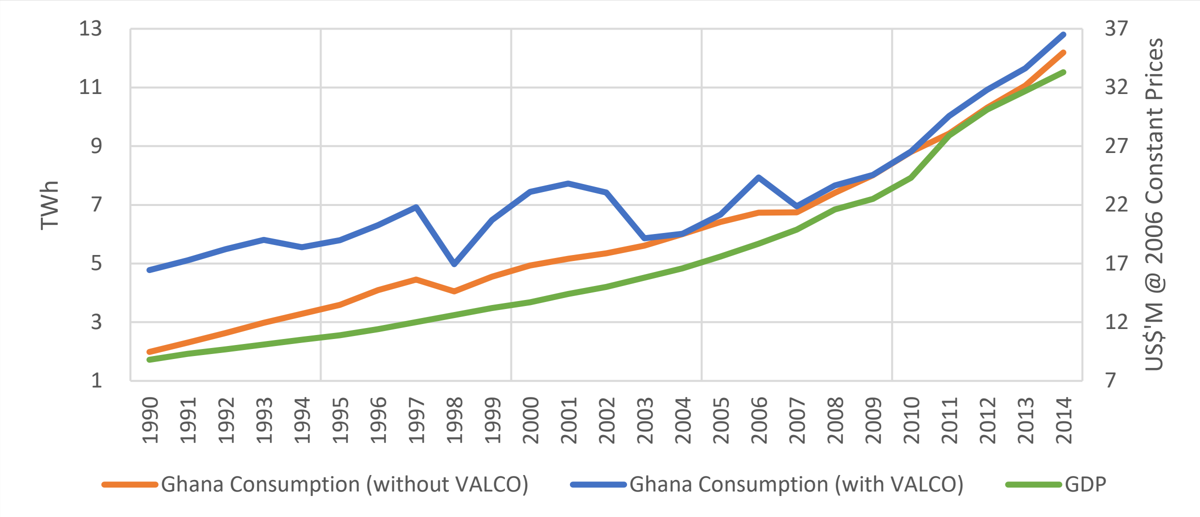



Figure 6: Impact of VALCO on GDP
Source: ICF Analysis based on data from VRA and GSS

Ghana electricity consumption without VALCO correlates well with total GDP. However, the addition of VALCO consumption to the consumption does not seem to improve the relationship with GDP. One major factor that affects the economic viability of VALCO's operation, among others, is the cost of electricity. Economic viability of VALCO requires power prices much lower than what prevails in Ghana today. Therefore, the assumptions behind VALCO's consumption in load forecasts need to be studied more carefully.

Over the years, projections for VALCO have varied based on information gathered by institutions. For instance whereas the GRIDCo Transmission Master Plan assumed no potline to be in operation from 2010 to 2012, the Generation Master Plan started with 2 potlines in 2011 and 3 potlines afterwards.

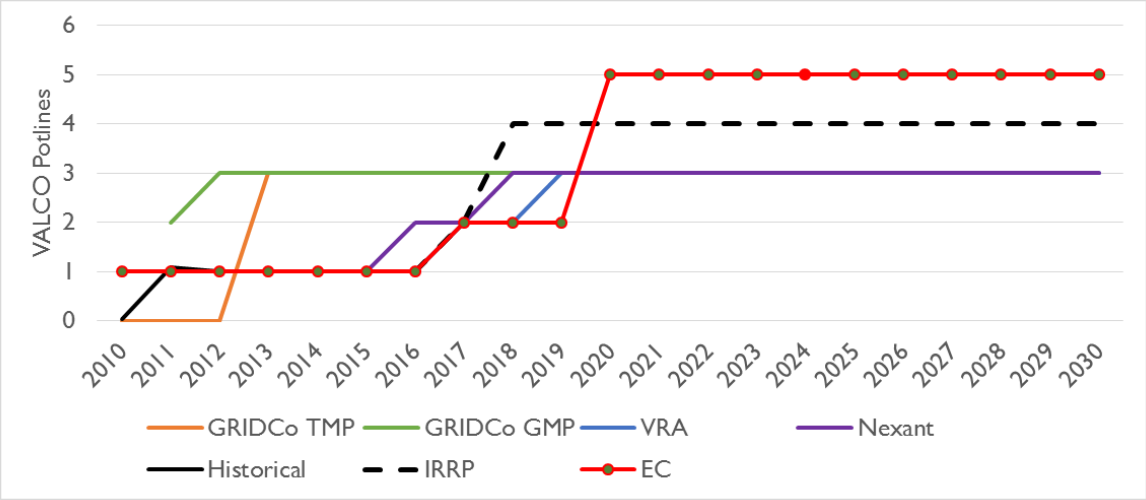



Figure 7: Comparison of VALCO Potline Assumptions
Source: Existing Forecast Reports

## 4.2 NET EXPORT DEMAND

Ghana has power supply transactions with its neighbouring countries namely I'voiry Coast, Burkina Faso, and Togo/Benin. Historically, Ghana has been a net importer until recent years. As shown in Figure 8, Ghana became a net exporter in 2008 and this trend has been sustained over the years. Net exports peaked in 2010 where it rose to about 930W. Generally, although Ghana relies on imports from Ivory Coast during periods of generation shortfalls, its exports to SONABEL of Burkina Faso, CEB of Togo/Benin and sometimes CIE of Cote D'Ivoire outweighs imports from CIE. Figure 8 illustrates historical net exports in Ghana.

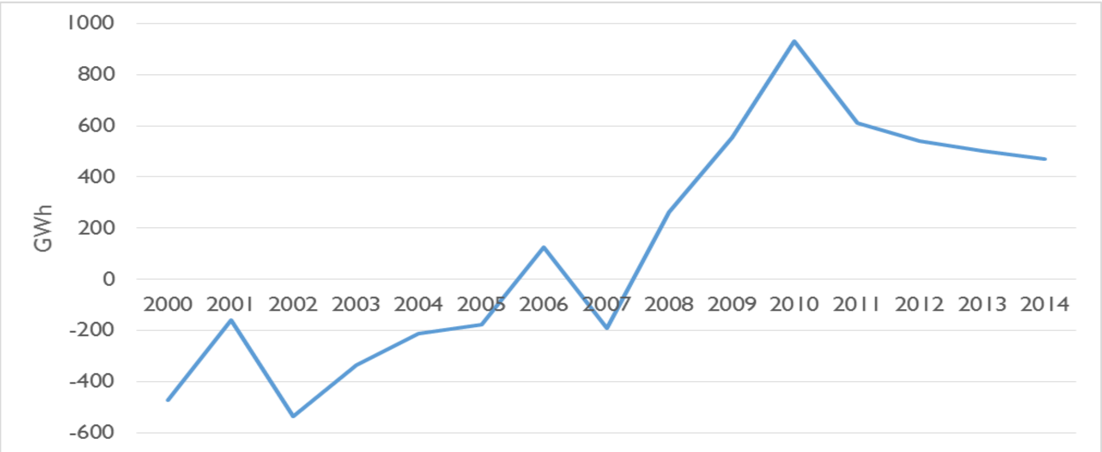



Figure 8: Historical Ghana Net Exports
Source: GRIDCo TMP, 2011

Electricity demand projections for net exports in Ghana are primarily based power supply contracts between Ghana and its neighbouring countries namely I'voiry Coast, Burkina Faso, and Togo/Benin. These power supply contracts are reviewed on an ongoing to reflect the changing demands of the countries. Consequently, forecasts made in the reviewed reports for imports and exports vary per the information gathered by the institution conducting the forecast at the time of the forecast.

The IRRP Team in consultation with GRIDCo, developed initial energy demand forecasts for exports to Togo/CEB, Burkina Faso, CIE. Energy Demand Projects to CIE were based on the VRA base case assumption for exports to CIE. In forecasting imports, CIE was assumed to supply only energy and not peak demand.

Table 3: IRRP Energy Demand Forecast for Exports

| Year | Energy | | | Peak | | |
|---|---|---|---|---|---|---|
| | Togo/CEB | Burkina | CIE | Togo/CEB | Burkina | CIE |
| | GWh | GWh | GWh | MW | MW | MW |
| 2016 | 384 | 42 | 10 | 100 | 5 | 3 |
| 2017 | 384 | 42 | 10 | 100 | 5 | 3 |
| 2018 | 392 | 42 | 10 | 102 | 6 | 3 |
| 2019 | 400 | 42 | 10 | 104 | 6 | 3 |
| 2020 | 408 | 42 | 10 | 106 | 6 | 3 |
| 2021 | 416 | 389 | 10 | 108 | 71 | 3 |
| 2022 | 424 | 520 | 10 | 110 | 91 | 3 |
| 2023 | 432 | 655 | 10 | 113 | 111 | 3 |
| 2024 | 441 | 795 | 10 | 115 | 131 | 3 |
| 2025 | 450 | 939 | 10 | 117 | 152 | 3 |
| 2026 | 459 | 1,069 | 10 | 120 | 172 | 3 |
| 2027 | 468 | 1,203 | 10 | 122 | 192 | 3 |
| 2028 | 477 | 1,342 | 10 | 124 | 212 | 3 |
| 2029 | 487 | 1,485 | 10 | 127 | 233 | 3 |
| 2030 | 497 | 1,633 | 10 | 129 | 253 | 3 |

Source: IRRP Analysis

## 5. NEXT STEPS

The IRRP team will be working with the team responsible for the preparation of the GRIDCo Supply Plan to ensure consistency in methodology and assumptions and ultimately, demand projections. This is to consolidate the work of the IRRP team in developing a consensus reference case demand forecast for the IRRP modelling. The IRRP team also look forward to analysing the role of electricity price and self-generation as well as the impacts of climate change, EE, DSM on demand drivers in the future.

# 6. APPENDIX: DETAILED REVIEW OF LOAD FORECAST REPORTS

## 6.1 VRA Load Forecast Final Report, October 2014

VRA developed a sixteen year (2015 to 2030) load forecast for six categories of its customers namely ECG, NEDCo, Direct Sales to the Mines supplied by VRA (VRA mines), Other Direct Sales within Ghana (including VRA Townships), VALCO Smelter and Exports to neighbouring countries (Togo, Benin and Burkina Faso). Whereas regression analysis was used to forecast the load of ECG and NEDCo, forecasts for VRA mines and other direct customers were based on customer surveys. VALCO's forecast was based on some assumptions made on the number of operational potlines and load forecast for exports was based on the power supply contracts with these countries.

In developing the regression models for ECG and NEDCo, VRA used GDP and population as dependent variables. GDP was used as substitute for income and the population was the respective number of customers for ECG and NEDCo. A correlation analysis was performed on input data from 1990 to 2010 which showed a high correlation between population and GDP. As a result, population was dropped from the regression model and GDP was the only explanatory variable used in the model. According to the forecast report, ECG sales was regressed on the *GDP of the previous 2 years* whereas NEDCo sales was regressed on the GDP of the year in question due to a high R-squared observed between these variables. Below are the regression models obtained for ECG and NEDCo respectively:

- ECG Sales = 368.72(GDP-2) – 1012.82
- NEDCo Sales = 34.22(GDP) – 169.79

The GDP data used was obtained from the IMF at 2006 constant USD prices. The IMF report provided GDP forecast up to year 2019. For the base case scenario forecasts, VRA used the IMF forecasts and further used a moving average method to extrapolate GDP forecasts for years 2020 to 2030 based on the growth rates for 2013 to 2019. For the low case scenario, VRA assumed a GDP growth rate of 4.69% which is the average of 3 of the lowest growth rates recorded over the last 10 years. To derive growth rates for the high case scenario, VRA added 2% to each base case rate.

To forecast for the mines and other direct customers, VRA conducted a survey to gather information on their operations and future expansion plans. Based on information gathered, VRA using their expert judgement developed a load forecast for the mines and other direct customers. A similar approach was used to develop forecasts for exports to CEB of Togo/Benin, SONABEL of Burkina Faso and Youga Mine also of Burkina Faso, taking cognizance of the contract with these countries. VALCO's load forecast was based on an assumed number of potlines to be in operation. The assumptions made are discussed in Section 6.8.

After forecasts of energy had been made for each customer category, VRA estimated peak demand forecasts by using load factors. Table 4 presents the load factor used for each customer.

Table 4: VRA Forecast Report – Load Factors Used

| Customer | Load Factor |
|---|---|
| ECG | 64.23% |
| NEDCo | 64.70% |
| VALCo | 94.36% |
| Mines | 71.64% |
| Other direct customers | 64.39% |
| Exports | 100.00% |

Source: VRA Load Forecast Final Report, October 2014

### 6.2 GRIDCO Generation Master Plan Study For Ghana, November 2011

The Generation Master Plan Study for Ghana was undertaken by Tractebel for GRIDCo. As part of the study, a fifteen year (2011 to 2026) load forecast was developed for Domestic load, VALCO and Exports. Regression analysis was used to forecast the load for domestic consumption, and that of VALCO and export forecasts were based on information gathered by Tractebel from GRIDCo.

To determine what dependent variables to use in the regression model for domestic consumption, the Tractebel performed correlation analysis on different combinations of macroeconomic parameters to identify the variable with the strongest relationship with total domestic energy consumption. The parameters used were total number of Ghana population (population), GDP (at 2000 constant GHS prices), GDP per Capita (in GHS), and energy generated. Input data from 2000 to 2010 was used for the analysis. Ultimately, population, GDP per capita and GDP+1 (the GDP of the next year) were used as the variables for the regression analysis due to its high correlation with domestic consumption. The regression model was estimated as:

- Domestic Consumption = 2629.13 + 2.35(GDP+1) – 144.82(Population) – 11.45(GDP per capita)

To forecast domestic consumption, the following growth rate assumptions were made for GDP.

Table 5: Generation Master Plan GDP Growth Rate Assumptions

| Year | Low | Base | High |
|---|---|---|---|
| 2011 | 6.9% | 9.90% | 12.90% |
| 2012 | 4.9% | 7.00% | 9.10% |
| 2013 | 4.4% | 6.30% | 8.20% |
| 2014 | 4.2% | 6.00% | 7.80% |
| 2015 | 4.1% | 5.80% | 7.50% |

| | | | |
|---|---|---|---|
| 2016 to 2026 | 4.10% | 5.80% | 7.50% |

Source: GRIDCO Generation Master Plan, November 2011

Growth rate assumptions for GDP were derived from the IMF from 2010 to 2015. Tractebel then used the trend from 2010 to 2015 to forecast for the remaining period (2016 to 2026). For population growth rates, the study assumed 1.8%, 2.6%, 3.3% for the low, base and high case scenarios respectively, for the entire forecast period.

Forecasts for VALCO were based on assumptions made on the number of potlines expected to be in operation. This is discussed further in Section 6.8. Peak loads were forecasted from Energy forecasts using load factor of 70% based on historic data.

The report further developed geographic demand forecasts for each existing [and new] substations, mine and direct customer based on transmission constraints as per the Transmission Master Plan. The geographic load forecast carried out in the Generation Masterplan is only an extension of what was done in the Transmission Masterplan; the consultant used growth rates to forecast the load for each substation for the period 2021 to 2026 (i.e. the period not covered by the Transmission Plan). Details of the geographic load forecast are presented under the Transmission Master Plan review below.

### 6.3 GRIDCO Transmission Master Plan Study For Ghana, February 2011

Prior to developing the Generation Master Plan, Tractebel developed a Transmission System Master Plan for Ghana. As part of this study, electricity demand projections for the period 2010 to 2020 was undertaken for the following categories of customers: Domestic consumption, VALCO and Exports. Similar to the Generation Master Plan, regression analysis was used to forecast the load for domestic consumption and that of VALCO and export forecasts were based on information gathered by Tractebel from GRIDCo.

Correlation analysis was performed on different combinations of macroeconomic parameters to identify the variable(s) with the strongest relationship with total domestic energy consumption for use in the regression model for domestic consumption. The dependent variables used in the correlation analysis were total Ghana population (population), GDP (at 2000 constant GHS prices), GDP per capita, energy generated. Data from 1992 to 2009 was used as input for the correlation study. Ultimately, only GDP was used as the explanatory variable for the regression analysis due to its high correlation with domestic consumption. The regression model was estimated as:

- Domestic Consumption = 0.21(GDP) -1072

To forecast domestic consumption, the following assumptions were made.

Table 6: Transmission Master Plan GDP Growth Rate Assumptions

| Year | Low | Base | High |
|---|---|---|---|
| 2010 | 4.3% | 6.2% | 8.1% |
| 2011 | 4.3% | 6.2% | 8.1% |
| 2012 | 4.3% | 6.2% | 8.1% |
| 2013 | 4.1% | 5.9% | 7.7% |
| 2014 to 2020 | 4.3% | 6.1% | 8.0% |

Source: GRIDCO Transmission Master Plan Study, February 2011

The GDP growth rate assumptions from 2010 to 2014 were derived from IMF projections for Ghana. The trend from 2010 to 2014 was then used to forecast for years 2015 to 2020.

Load forecasts made for VALCO are discussed in Section 6.8. To convert the energy forecast to peak load, a load factor of 70% was used. The report further developed geographic demand forecasts for each existing [and new] substations, mine and direct customer based on transmission constraints. The country was zoned into 5 regions namely:

- Greater Accra and parts of Eastern
- Central and Volta Regions
- Western Region and part of Central Region
- Ashanti Region and part of Eastern Region
- Brong Ahafo Region
- Northern, Upper West and East Regions.

The consultant used growth rates to forecast the load for each substation for the forecast period. The growth rates used was based on historic growth trends between 2000-2006, adjusted for factors such as suppressed demand, mines, etc. Subsequently, the demand for each substation was added to obtain the yearly load demand for each zone for the entire forecast period. Cross checks were also carried out to ensure that the sum of coincident peaks of the each substation corresponded to the global peak load forecast.

For the purposes of the IRRP Project, the basis of geographical/regional breakout would be reconsidered. In line with this objective the IRRP team is working with GSS to conduct analysis to derive a proxy composite index that gives information about economic output at regional levels because GSS has no explicit data on regional GDP.

### 6.4 ECG 2015 Load Forecast Report, October 2015

ECG developed a ten-year (2015 to 2024) load forecast for its two main customer groups namely Special Load Tariff (STL) customers and Non-Special Load Tariff (NSLT) customers, for three scenarios. Whereas multiple linear regression analysis was used for NSLT, the SLT model employed the method of Autoregressive. Both analysis was performed with EVIEWS software.

The explanatory variables used for the NSLT regression analysis are:

- Real average non-SLT price (LNP_NSLT),
- Total GDP (LNGDP),

- NSLT customer population (LNPOP_NSLT), and
- Dip in sales dummy variable (DMN)

The IRRP team identified the choice of explanatory variables as very problematic as these variables are highly correlated. The dip in sales dummy variable was introduced to correct for years that witnessed significant dip in energy sales due to load shedding. Input data from 1994 to 2014 was used in estimating the coefficients of each variable. To account for suppressed demand, the actual sales value for 2014 was replaced with the 2014 forecast value in the 2014 Forecast Report. The NSLT regression model was estimated as:

- LNS_NSLT=0.302(LNPOP_NSLT) – 0.129(LNP_NSLT) + 0.711(LNGDP) – 0.06(DMN) - 5.66

To forecast for the period 2015 to 2024, the following growth rate assumptions were used

Table 7: ECG 2015 - NSLT Growth Rate Assumptions

| Dependent Variable | 2015 to 2019 | | | 2020 to 2024 | | |
|---|---|---|---|---|---|---|
| | Low | Base | High | Low | Base | High |
| Non-SLT Customer Population | 8.38 | 12.38 | 16.38 | 8.38 | 12.38 | 16.38 |
| Non-SLT Real Price | 11.00 | 8.00 | 5.00 | 10.00 | 7.00 | 4.00 |
| Total GDP | 4.71 | 6.71 | 8.71 | 3.52 | 5.52 | 7.52 |
| Dip in Sales (Dummy) | 0 | 0 | 0 | 0 | 0 | 0 |

Source: ECG 2015 Load Forecast Report, October 2015

In assessing correlations between demand and price, the IRRP team interviewed the ECG load forecast team to understand how the real average NSLT price was computed. It was discovered that the NSLT price was computed by dividing billed energy sales revenue in GHS by energy sales in MWh, adjusted for inflation using CPI with 2006 as base year. From the information gathered, ICF graphed the real average NSLT price and monthly consumption per NSLT customer as shown below.

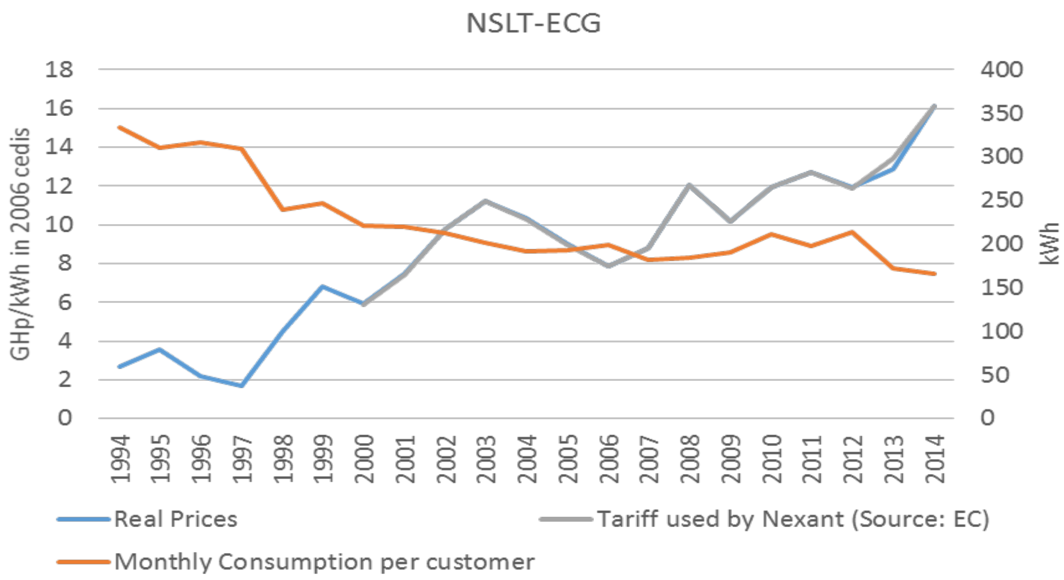



Figure 9: Demand-Price Correlation

One may infer from the above graph that the reduction in average monthly consumption is explained only by price increases. However, this might not be reflective of the true scenario for reasons such as impact of electrification and metering, energy consumption of the various customer categories by tariff class, data quality issues, etc. In order to conduct more meaningful analysis, there is the need for more granularity and breakdown by customer classes.

For the SLT model which used autoregressive analysis, the following explanatory variables were used.

- Lag of sales (LNS_SLT-1)
- GDP for services and industrial sector (LNGDPI)
- SLT customer population (LNPOP_SLT)
- Dip in SLT energy sales dummy variable (DMS)

The non-agric GDP (GDP for services and industrial sector) was used as a proxy for the income of SLT customers as income data was not available. Similar to the SLT model, the dip in sales dummy variable was introduced to correct for years that witnessed significant dip in energy sales due to load shedding. Input data from 1998 to 2014 for the above variables were used to develop the model. Similar to the NSLT analysis the actual sales value for 2014 was replaced with the 2014 forecast value in the 2014 Forecast Report to account for suppressed demand. The following regression model was obtained

- LNS_SLT=0.018(LNPOP_SLT) + 0.292(LNGDPI) – 0.101(DMS) + 0.537(LNS_SLT-1) – 0.355

To forecast for the period 2015 to 2024, the following assumptions were used

Table 8: ECG 2015 - SLT Growth Rate Assumptions

| Dependent Variable | 2015 to 2019 | | | 2020 to 2024 | | |
|---|---|---|---|---|---|---|
| | Low | Base | High | Low | Base | High |
| Non-Agric GDP | 5.21 | 9.21 | 13.21 | 4.41 | 8.41 | 12.41 |
| SLT Customer population | 7.04 | 12.04 | 17.04 | 5.65 | 10.65 | 15.65 |
| Dip in Sales (Dummy) | 0 | 0 | 0 | 0 | 0 | 0 |

Source: ECG 2015 Load Forecast Report, October 2015

The report mentioned that GDP data (in 2006 constant GHS) used in the analysis were obtained from the IMF. Growth rate assumptions beyond IMF projections was based on a trending method. The details were however not provided in the report. Customer population growth rates were based on historical trend. After forecasts of energy had been made for each customer category, ECG estimated peak demand forecasts by using load factors. The load factors used were however not presented in the report.

### 6.5 NEDCo Long Term Load Forecast, April 2015

NEDCo's long term forecast was developed for the period 2015 to 2024 for the entire customer population using regression analysis. NEDCo did not segregate their customer base. To develop the forecast model, the following explanatory variables were used:

- Total customer population,
- GDP per capita,
- Average end-user tariff (price), and
- Total system losses.

Similar to the problem of correlated variables identified in the ECG report, the use of GDP per capita and population as independent variables in one regression analysis does not lend itself to correct econometric modelling. Input data used was for the analysis was from 2000 to 2014. To account for energy crises however, the actual energy sales values for years 2006 and 2007 were replaced with previous forecast. GDP data used was obtained from the IMF database in constant 2006 cedis. The end-user price, based on tariffs gazetted by the Public Utilities Regulatory Commission (PURC), was used as a proxy for price in the model.

- Energy Sales = 1.0441(Population) + 2.7140(Price) + 0.1307(GDP/capita) + 6.8528(System Loss) – 76.6472

To develop forecasts for 2015 to 2024, NEDCo assumed growth rates for population, tariff and system losses. For GDP per capita, growth rates used for 2015 to 2019 was based on IMF Country Data 2014 report (No. 14/129). That of 2020 onwards was estimated at 4.7%. Customer population was assumed to grow at 6.5% and that of tariff was assumed to grow at 7% for the entire forecast period.

## 6.6 NEXANT FORECAST

Nexant Inc. developed a sixteen (16) year demand forecast covering 2015 to 2030 for nine customer categories – Residential, Non-residential, Street Lighting, SLT Customers, Non-SLT Customers, Mines, Direct Customers, VALCO, and Exports. A suppressed demand analysis was carried out to develop an unconstrained demand for the 2012 – 2014 (period of major load shedding) period to be used as a starting point to forecast demand. For suppressed demand for domestic consumption, the report indicated that the Supply Constraint component of the suppressed demand was estimated to be 940GWh whereas the Infrastructure Barrier component was estimated to be 776GWh. When VALCO and exports are considered, total suppressed demand is estimated to be 6,000GWh or close to 50% of the 2014 supply.

Nexant first developed forecasts using regression models for customers connected to the distribution system (Residential, Non-residential, ECG Industrial Sales, NEDCo Industrial Sales). Distribution losses, infrastructure suppressed demand and estimated conversion of commercial losses to actual demand were then added to the distribution system sales forecast to arrive at the total demand forecast the distribution level. Forecast for street lighting was also made by fitting it to an S-Curve primarily because the available historical values could not be fit to a regression based model.

Forecasts were then developed for the customers connected at the transmission system (Mines, Direct Customers, VALCO, and Exports). With the exception of Direct Customers, demand for the other customer categories was not independently forecast but was based on forecasts from VRA, GRIDCo and the Energy Commission. Specifically, VALCO forecasts were based on GRIDCo and EC assumptions, whereas that of Mines was based on VRA forecasts. Similarly, system usage and transmission losses were based on GRIDCo estimates. The total system forecast was arrived at by adding demand forecasts at the distribution and transmission levels to system usage and transmission loss levels.

In developing the regression models, different combinations of a set of independent variables were tested for each of the distribution level customer category (Residential, Non-residential, ECG Industrial Sales, NEDCo Industrial Sales). The set of independent variables consisted of:

- Total Ghana Population (POP_TOT)
- Population of Active SLT Customers (POP_SLT)
- Population of Active Non Residential Customers (POP_NON_RES)
- Population of Active Residential Customers (POP_RES)
- Average Household Size (A_HOUSE)
- Total Gross Domestic Product (GDP)
- Industrial Component of GDP (GDPI)
- Services Component of GDP (GDPS)
- Agriculture Component of GDP GDPA
- End User Tariff for Non SLT Customer P_NSLT
- End User Tariff for SLT Customers P_SLT
- SLT Customer Sales S_SLT

- NSLT Customer Sales S_NSLT
- Per Capita Income GDP/Population

For some customers also, Nexant used N-1 and a dummy variable as part of the independent variables. Input data from 2000 to 2014 was obtained for the above variables and adjusted to account for suppressed demand. GDP data was from GSS in constant 2006 USD prices. Based on available GDP projections, Nexant developed growth rate assumptions for GDP.

After regressions were done, using XLSTAT, on different combinations of the independent variables for each customer category, only models with high R-squared values and with coefficients which are of reasonable magnitude and sign as well as low P-values were accepted for inclusion in the model. The regression models for Residential, Non-residential, SLT Customers, Non-SLT Customers, and Direct Customers is presented below:

- LN(RES) = -6.79 + 0.699*LN(GDP) – 0.042*LN(P_NSLT)-1.261*LN(A_HOUSE) – 0.049*DUMMY
- LN(NON_RES) = -16.634 + 0.931*LN(GDPS) – 0.115*LN(P_NSLT) + 0.382*LN(NON_RES N-1) – 0.099*DUMMY
- LN(SLT) = 1.014 + 0.451*LN(POP_SLT) + 0.434*LN(SLT N-1) – 0.065*DUMMY
- LN(NSLT) = -15.597 + 0.973*LN(GDP) – 0.112*LN(P_NSLT) + 0.137*LN(NSLT N-1) – 0.054*DUMMY
- LN(DIR) = -6.278 + 0.353*LN(GDPI) + 0.691*LN(DIR N-1)

Future growth rate assumptions were then developed based historical trend and available best estimates from other institutions. The growth rate assumptions is tabulated below.

Table 9: Growth Rate Assumptions Used in Nexant Forecast

| Forecast Period | 2015 - 2018 | | | 2019 - 2024 | | | 2025 - 2030 | | |
|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Low** | **Base** | **High** | **Low** | **Base** | **High** | **Low** | **Base** | **High** |
| Total GDP | 6.80% | 7.20% | 8.20% | 5.80% | 6.20% | 7.50% | 5.00% | 5.50% | 7.20% |
| Price | 4.00% | 6.00% | 8.00% | 2.00% | 4.00% | 6.00% | 1.00% | 2.00% | 4.00% |
| Total Population | 1.90% | 2.30% | 2.60% | 1.90% | 2.30% | 2.60% | 1.90% | 2.30% | 2.60% |
| No. of Residential Customers | 6.00% | 8.00% | 10.00% | 5.00% | 6.00% | 7.00% | 4.00% | 4.50% | 5.00% |
| No. of Non-Residential Customers | 8.00% | 10.00% | 12.00% | 7.00% | 8.00% | 10.00% | 6.00% | 7.00% | 9.00% |
| No. of ECG and NEDCo SLT Customers | 8.00% | 10.00% | 12.00% | 7.00% | 8.00% | 10.00% | 6.00% | 7.00% | 9.00% |

Source: USAID/Nexant Electricity Demand Forecasting and Suppressed Demand Estimation Study

After projections were made for energy, peak load forecast was derived by converting the energy projections using assumed future coincident factors for Ghana consumption, VALCO and Exports. The assumptions for coincident factors for Ghana consumption was based on historical data. Future coincident peak load factors for VALCO and Exports were based on assumptions made by EC and GRIDCo. The assumed coincident factors is presented in Table 10.

Table10: Assumptions for Future Coincident Factors

| Period | Ghana Load at Peak | VALCO | Exports |
|---|---|---|---|
| 2015 - 2030 | 72.1% | 95.1% | 75% |

### 6.7 EC Forecast

The EC developed a forecast for electricity demand for the period 2016 to 2035. As stated earlier, the Energy Commission uses a buttom-up approach using LEAP model for its demand forecast. ICF, upon receipt of the draft SNEP report from the EC, reviewed all electricity-related content and submitted its comments on the said report. As stated earlier, the SNEP developed two scenarios called the Business-As-Usual (BaU) – which compares with the base case scenarios in the other reports – and Accelerated Economic Growth (AEG). The key drivers and assumptions used in developing these forecasts were based on demographic factors, macro-economic parameters, and government policies and interventions. Electricity demand projections were developed for six (6) sectors namely household, services, industry, VALCO, agriculture, and transport. Table shows some of the growth rate assumptions used for both scenarios

Table 11: Growth rate assumptions used in EC electricity demand projections

| Variable | BaU | AEG |
|---|---|---|
| GDP | 7.10% | 8.30% |
| GDP per capita | 5.2% | 6.6% |
| Population | 2.10% | 2.0% |
| Urbanization | 69.1% | 70.4% |

Source: SNEP, Energy Demand Projections for Ghana; Final Draft II

Peak demand was estimated by converting energy to peak using load factors.

### 6.8 VALCO Assumptions

As noted in earlier, demand forecast for VALCo were based on assumptions on the number of potlines in operation for the forecast period. Each potline requires about 75MW at full capacity. A summary of the assumed number of VALCO potlines to be in operation for each report is presented in Table 12.

Table 12: Assumptions for number of potlines in operation

| Scenario | Institution | Forecast Period | Assumption |
|---|---|---|---|
| High Case | VRA | 2015 to 2016 | 2 |
| | | 2017 | 3 |
| | | 2018 | 4 |
| | | 2019 to 2030 | 5 |
| | GRIDCo Transmission Plan | 2010 to 2012 | 0 |
| | | 2013 to 2020 | 4 |
| | GRIDCo Generation Plan | 2011 to 2012 | 2 |
| | | 2013 to 2026 | 4 |
| | Nexant | 2015 | 1 |
| | | 2016 - 2017 | 2 |
| | | 2018 | 3 |
| | | 2019 - 2030 | 5 |
| | IRRP | 2016 | N/A |
| | | 2017 | N/A |
| | | 2018 - 20130 | N/A |
| | EC | 2010-2016 | 1 |
| | | 2017 - 2019 | 2 |
| | | 2020-2035 | 5 |
| Base Case | VRA | 2015 to 2016 | 1 |
| | | 2017 | 2 |
| | | 2018 | 2 |
| | | 2019 to 2030 | 3 |
| | GRIDCo Transmission Plan | 2010 to 2012 | 0 |
| | | 2013 to 2020 | 3 |
| | GRIDCo Generation Plan | 2011 to 2012 | 2 |
| | | 2013 to 2026 | 3 |
| | Nexant | 2015 | 1 |
| | | 2016 - 2017 | 2 |
| | | 2018 | 3 |
| | | 2019 - 2030 | 5 |
| | IRRP | 2016 | 1 |
| | | 2017 | 2 |
| | | 2018 - 20130 | 4 |
| | EC | 2010-2016 | 1 |
| | | 2017 - 2019 | 2 |
| | | 2020-2035 | 5 |
| Low Case | VRA | 2015 to 2016 | 1 |
| | | 2017 | 1 |

| | | | |
|---|---|---|---|
| | | 2018 | 2 |
| | | 2019 to 2030 | 2 |
| | GRIDCo Transmission Plan | 2010 to 2012 | 0 |
| | | 2013 to 2020 | 2 |
| | GRIDCo Generation Plan | 2011 to 2012 | 1 |
| | | 2013 to 2026 | 2 |
| | Nexant | 2015 | 1 |
| | | 2016 - 2017 | 2 |
| | | 2018 | 3 |
| | | 2019 - 2030 | 5 |
| | IRRP | 2016 | N/A |
| | | 2017 | N/A |
| | | 2018 - 20130 | N/A |

Source: Existing load forecast reports in Ghana

Assumptions for VALCO vary in all three forecast reports. Given that the Transmission and Generation Master Plan studies were undertaken by the same consultant around the same period (one-year interval), one may expect that assumptions for VALCO should have similar forecasts. As shown in Table 12 above, this was not the case. This could be explained primarily by the information made available to the consultant especially on efforts that were being made to resume operations at VALCO.

## 6.9 IRRP REFENCE CASE DEMAND ESTIMATES FOR ECG AND NEDCO

Table 13: ECG Energy Demand Projections for ECG broken into IPM Model Regions

| YEAR | ASHANTI | SOUTH EAST | SOUTHWEST | TOTAL |
|---|---|---|---|---|
| | GWh | GWh | GWh | GWh |
| 2016 | 1,518 | 5,869 | 1,608 | **8,996** |
| 2017 | 1,608 | 6,230 | 1,697 | **9,535** |
| 2018 | 1,715 | 6,686 | 1,789 | **10,190** |
| 2019 | 1,807 | 7,084 | 1,868 | **10,760** |
| 2020 | 1,867 | 7,427 | 1,920 | **11,214** |
| 2021 | 1,975 | 7,658 | 1,974 | **11,607** |
| 2022 | 2,115 | 8,048 | 2,054 | **12,216** |
| 2023 | 2,236 | 8,475 | 2,127 | **12,838** |
| 2024 | 2,335 | 8,921 | 2,189 | **13,445** |
| 2025 | 2,407 | 9,410 | 2,242 | **14,059** |
| 2026 | 2,496 | 9,912 | 2,301 | **14,710** |
| 2027 | 2,595 | 10,463 | 2,367 | **15,424** |
| 2028 | 2,694 | 11,034 | 2,432 | **16,161** |
| 2029 | 2,796 | 11,629 | 2,497 | **16,923** |
| 2030 | 2,901 | 12,254 | 2,564 | **17,720** |

Source: IRRP Analysis

Table 14: IRRP Peak Demand Projections for ECG broken into IPM Model Regions

| Year | ASHANTI | SOUTH EAST | SOUTH WEST | TOTAL |
|---|---|---|---|---|
| 2016 | 311 | 890 | 271 | **1,473** |
| 2017 | 331 | 945 | 285 | **1,561** |
| 2018 | 350 | 1,018 | 300 | **1,668** |
| 2019 | 368 | 1,082 | 312 | **1,762** |
| 2020 | 383 | 1,137 | 316 | **1,836** |
| 2021 | 398 | 1,178 | 324 | **1,900** |
| 2022 | 429 | 1,236 | 336 | **2,000** |
| 2023 | 454 | 1,302 | 346 | **2,102** |
| 2024 | 476 | 1,373 | 353 | **2,201** |
| 2025 | 489 | 1,453 | 360 | **2,302** |
| 2026 | 507 | 1,534 | 367 | **2,408** |
| 2027 | 527 | 1,623 | 375 | **2,525** |
| 2028 | 547 | 1,716 | 383 | **2,646** |
| 2029 | 568 | 1,813 | 390 | **2,771** |
| 2030 | 589 | 1,914 | 398 | **2,901** |

Table 15: IRRP Peak and Energy Demand Estimates for NEDCo

| Year | NEDCO Forecast | |
|---|---|---|
| | MW | GWh |
| 2016 | 179 | 1,091 |
| 2017 | 204 | 1,196 |
| 2018 | 226 | 1,328 |
| 2019 | 245 | 1,447 |
| 2020 | 260 | 1,545 |
| 2021 | 273 | 1,631 |
| 2022 | 296 | 1,768 |
| 2023 | 320 | 1,913 |
| 2024 | 344 | 2,058 |
| 2025 | 370 | 2,208 |
| 2026 | 397 | 2,371 |
| 2027 | 428 | 2,556 |
| 2028 | 460 | 2,751 |
| 2029 | 495 | 2,959 |
| 2030 | 533 | 3,182 |

Source: IRRP Analysis

# E. Supply Workshop Report

In November 2016, the IRRP project held a workshop on assessing the supply situation in Ghana in terms of existing capacity and planned/potential expansion options for Ghana. The agenda and proceedings of the workshop are provided below.

Following the workshop, information about supply options were included in the Integrated Planning Model, and regularly updated.

**Integrated Resource and Resilience**
**Planning (IRRP) Project**
**Agenda for IRRP Discussion Forum on Power Supply Options**

**November 10, 2016**

| | |
|---|---|
| **8:30 – 9:00** | **Arrival and Registration** |
| **9:00 – 9:05** | **Introduction and Welcome** – Ananth Chikkatur, Chief of Party, IRRP Project |
| **9:05 – 9:10** | **Opening remarks By Chief Director, Ministry of Power** |
| **9:10 – 9:20** | **Overview of Agenda and Objectives of the Forum**<br>Michael Opam, Executive Secretary, Energy Commission<br>Jabesh Amissah-Arthur, Chairman of JUC |
| **9:20 – 10:00** | **Context: State of Current Large Hydropower in Ghana**<br>**VRA** (*Kwaku Wiafe*) –Available capacity and future output of Akosombo and Kpong; Hydrological conditions, reservoir cycles, etc.; Impact of droughts and climate change on future output; Maintenance and operation costs<br>**BPA** (*Peter Acheampong*) – Available capacity and future output of Bui; Hydrological conditions, reservoir cycles, etc.; Impact of droughts and climate change on future output; Maintenance and operation costs |
| **10:00 – 11:00** | **Natural Gas Resource and Production**<br>• Talk 1: **MoPET** (Prof. Thomas Akabzaa/Lawrence Apaalse) – Gas Master Plan, and policy implications for power sector planning; Policies for LCO/Diesel import; Role of TOR<br>• *Talk 2:* **GNPC** (*Alex Mould*) – Ghana gas resource potential; Production volumes and timing; LNG import plans; Pricing of domestic gas and LNG for power plant consumers; Costs and risks of importing HFO/LCO;<br>• *Talk 3:* **PURC** (*S. Sarpong*) – Natural gas processing and transportation tariffs in Ghana; Regulation and delivered cost of domestic gas and LNG to power plants, based on potential pricing options |
| **11:00 – 11:15** | Discussion |
| **11:15 – 11:30** | Coffee Break |
| **11:30 – 12:45** | **Renewable Energy Resources and Potential Power plants**<br>• *Talk 1*: **MoP** (Wisdom Tagobo-Ahiataku) – Overview of renewable energy in Ghana; Current plants and planned project; potential renewable energy sources (small/mini hydro, solar insolation, wind, biomass, etc.; Timing, cost, and performance of existing, planned, and potential projects; Challenges for grid-connected solar and wind power development<br>• *Talk 2*: **BPA**– Small/Mini hydro power potential on the Black Volta; Conversion from resources to potential power plants on the Black Volta; Location, cost and performance of potential projects; Challenges for implementation<br>• *Talk 3*: **VRA**– Small/Mini hydro power potential on the White Volta and the Oti River; Conversion from resources to potential power plants; Location, Cost and performance of potential projects; Challenges for implementation<br>• *Talk 4*: **EC** – Resource potential for biomass, tidal, waste and other renewable power generation in Ghana; Cost and performance of planned/potential projects; Challenges for implementation |

| | |
|---|---|
| **12:45 – 1:00** | Discussion |
| **1:00 – 1:45** | **Lunch Break** |
| **1:45 – 2:05** | **Coal Power Potential in Ghana**<br>• **VRA** (*Kwaku Wiafe*) – Current plans for coal-fired power plants in Ghana; Technology and costs; Environmental mitigation; Cost and infrastructure needs for coal imports |
| **2:05 – 2:25** | **Nuclear Power Potential in Ghana**<br>• **Ghana Atomic Energy Agency** (*Dr. Sogbadji*) – Review of IAEA requirements; Status of Ghana's submission to IAEA; potential timing, technology, and costs of nuclear power in Ghana; Handling of Spent fuel |
| **2:25 – 2:35** | **Discussion** |
| **2:35 – 3:00** | **Cost and Performance of various resources (Global perspective)**<br>• Maria Scheller and Ananth Chikkatur – Overview of cost and performance of various resources/technologies in the US and globally; risks and uncertainties; cost reductions in renewables and its implications; potential for new technologies |
| **3:00 – 3:20** | **Supply Stack using Simplified Levelized Cost Analysis**<br>• ICF/IRRP – Possible least cost buildup of supply options for Ghana, using LCOE approach; Implications for Ghana; Reasons for more sophisticated modeling |
| **3:20 – 3:45** | **Approaches for Least Cost Resource Selection for IRRP modeling**<br>• Maria Scheller, ICF |
| **3:45 – 4:00** | Discussion |
| **4:00 – 4:45** | **Environmental Impacts and Mitigation Measures**<br>• EPA/MESTI – Current and future environmental regulations impacting various resources (gas, coal, solar, wind, etc.) |
| **4:45 – 5:00** | **Closing Remarks**<br>• **Waqar Haider, USAID** |

# REPORT OF SUPPLY OPTIONS WORKSHOP

## NOVEMBER 9-10, 2016

Integrated Resource and Resilience Planning (IRRP) Project

# Contents

# 1 Background

The USAID/Ghana IRRP Project as part of the key activities for the modelling scenarios and forecasting, organized a workshop to assess the fuel resources options available for electricity generation in Ghana in the short, medium, and long-term. This workshop also aimed to provide training to stakeholders on the rudiments of these resources and what assumptions could be captured in the modelling, in terms of fuel supply planning. The agenda for the workshop was drafted with the idea of improving the knowledge-base all of the stakeholders involved in the IRRP project on the fuel options available to Ghana, which can enhance the quality of power planning for the country. It also provided the opportunity for the stakeholders to interact and discuss extensively the critical issues confronting the sector.

## 1.1 Opening Comments

The workshop was called to order at 9:30am by the Chief of Party (COP) of the IRRP Project, who moderated the workshop. He thanked all for making time to attend the workshop despite their very busy schedules. He was particularly encouraged by the keen interest taken by the Chief Director of the Ministry of Power (MOP) in the project, as indicated by his guidance in the planning of the workshop and his commitment to sit through all the sessions of the workshop. He encouraged all to remain committed not only to the workshop, but the broader IRRP project as well. Having made these comments, he invited the Chief Director to give his opening remarks to set the tone for the commencement of the main activities for the day.

***Chief Directors Opening remarks:***

The Chief Director of the Ministry of Power, Mr. Solomon Asoalla, thanked all the participants for their dedication to the IRRP project. He reiterated the Ministry's interest in the project activities, including the ultimate deliverables; and urged all to continue to contribute to their quota throughout the project life to make it a success. He ended by entreating all present to participate actively in all the discussions to produce a rich information needed to improve power supply planning in Ghana.

***Comments by Dr. NDK Asante on Objectives of IRRP & Agenda of the Supply Workshop:***

The Director of Technical Regulation of the Energy Commission, Dr. NDK Asante provided additional perspective to the workshop by highlighting the key issues that the workshop sought to address. He re-emphasized that the IRRP is focussed on the power sector, while the SNEP (which is prepared by the EC) focussed on all energy forms. Another key attribute of the IRRP was the inclusion of resiliency. He noted that unlike the individual plans prepared by the respective agencies, the IRRP is highly collaborative and represents shared ownership by the various stakeholders. Consequently, he expressed his optimism that the IRRP would cultivate a new basis for power planning in Ghana. Lastly, he implored the stakeholders to ensure that the ultimately, the IPSMP is pragmatic and implementable, and not just an aspirational plan.

***Comments by Jabesh Amissah Arthur on Objectives of IRRP & Purpose of the Supply Workshop***

Jabesh Amissah Arthur, CEO of Bui Power Authority, indicated how much the IRRP Project meant to the key stakeholders, hence a successful IRRP Project would ultimately benefit the Power Sector in particular and the Ghanaian economy in general. This was mainly because the future of the energy sector, depended in part on it.

The generation resources used to be 100% hydro just about two decades ago until thermal complementation set in. Currently, the percentage of hydro in the power generation mix is about 50% and the dynamics continue to change as more generation resources are progressively included in the mix. We are at a stage where there is real need for planning and this planning process is more complicated because of the options available. Again, thermal is not the obvious choice for capacity addition because of the increasing competiveness of renewables. In view of this, if there was going to be any meaningful addition from the IRRP, then it must go beyond the respective plans of the various agencies to produce something more comprehensive, integrated and beneficial to all stakeholders. It is also imperative to look at the associated financial challenges facing the sector in order to give the plan any chance of serving the needed purposes.

# 2 Attendance

The supply options workshop was well attended and with both day one and day two recording good participation from all the invited stakeholders which included Government of Ghana Agencies and Ministries, USAID, the ICF staff and other development partners. Day recorded effectively the same representation from the stakeholders with some variations in terms of numbers and personnel. Fifty One (51) people attended the Day One workshop while Forty one (41) were present on Day two.

## 2.1 Analysis of Participants

**Table 1** below provides a breakdown of the participants at the workshop. This is further illustrated in

**Figure 1** and **Figure 2** below for Day One and Day two respectively. Details of the attendees are in Annex A.

***Table 1: Gender Distribution of Participants***

| Day One | | | | Day Two | | |
|---|---|---|---|---|---|---|
| Male | Female | Total | | Male | Female | Total |
| 44 | 7 | 51 | | 34 | 7 | 41 |

***Figure 2: Gender disaggregation for Day One***

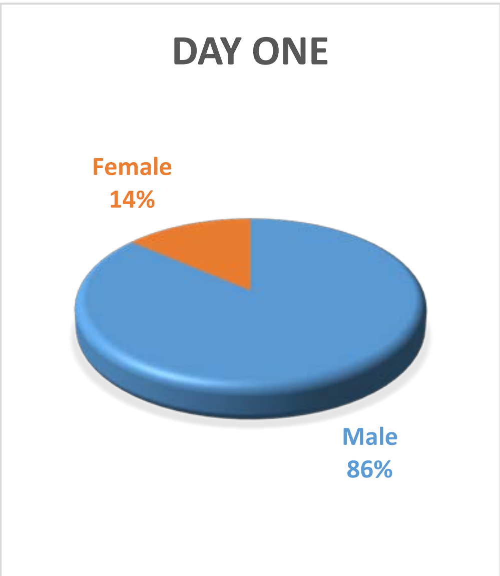
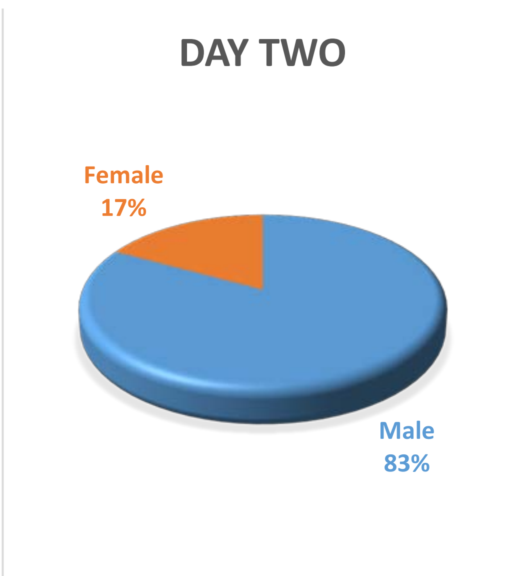



***Figure 1: Gender disaggregation for Day One***



# 3 Activities for Day One

The key items on the agenda for Day One followed the opening sessions and focussed on power generation resources in Ghana thus hydro, petroleum, and renewable energy resources. The presentations focussed on available resources, their potential, as well as related challenges and policies.

## 3.1 Highlights of Presentations for Day One

Below provides the key points in the presentations for Day One.

***Table 2: Highlights of Presentations on Day One***

| No. | Topic | Presenter | Highlights |
|---|---|---|---|
| 1 | State Of VRA Hydro Power Generation | Ing. Abdul N. Wahab, VRA | a. Characteristics of the VRA Hydropower Stations:<br>• Akosombo GS<br>• Kpong GS<br>b. Contribution of Hydro Power in Ghana's Energy Mix<br>c. Hydrological Conditions and Reservoir Cycle<br>d. Future hydro potential (Oti & White Volta Rivers)<br>e. • Challenges for Implementation |
| 2 | IRRP Workshop On Power Supply Options – Bui Generating Station | Kwadwo Brentuo Owusu, BPA | a. Energy Generation Regime at BPA<br>• Available Capacity & future output<br>• Hydrological conditions & reservoir cycle<br>• Droughts and Climate Change on future output<br>• Maintenance and Operation Costs<br>b. Potential of Small/Mini hydro power plants |
| 3 | Climate Change impacts on hydropower | Barnabas A. Amisigo, CSIR | a. Introduction – Ghana's freshwater resources<br>b. How CC can impact hydropower<br>c. Potential CC impacts on streamflows & hydropower<br>d. The case for resilience in the Energy Sector |
| 4 | Gas Master Plan (GMP) & Policy Implications For Power Sector Planning | Lawrence Apaalse, MoPET | a. Power Generation -Most commercially attractive with ready demand<br>b. Cement/Clinker Production -High netback but priority for cement clinker based on further studies on availability of limestone deposits |

| No. | Topic | Presenter | Highlights |
|---|---|---|---|
| | | | c. Industrial Co-Generation, power and heat applications<br>d. CNG Vehicles, to replace motor gasoline<br>e. Petrochemical Synthesis, for higher value addition |
| 5 | Ghana's Power Supply Options | Albert Akowuah, GNPC | a. Current state of gas in Ghana<br>b. Gas Resource Potential<br>c. Gas Production Volumes & Timing<br>d. LNG Import Plans<br>e. Cost of Fuels and Pricing of gas |
| 6 | Utility Provision & Regulation<br>For Natural Gas Transportation Tariff | Samuel Sarpong, Executive Secretary, PURC | a. Overview of PURC's Mandate<br>b. Overview of PURC's Natural Gas Transportation Tariff<br>c. Implementation Approach - Natural<br>d. Transportation Tariff |
| 7 | Renewable Energy Resources and Potential Power Plants | Wisdom Ahiataku –Togobo, MOP | a. Ghana Renewable Energy Policy Goal – 2030<br>b. Renewable Energy Resource Potential<br>c. Renewable Energy Policy Objectives<br>d. Priority Areas for Renewable Energy Investments (Grid Connected)<br>e. Development of Utility Scale RE projects<br>f. MOUs & PPAs Under Consideration (ECG)<br>g. Renewable Energy Purchase Obligation (REPO)<br>h. Priority Areas for Mini & Off Grid Renewable Energy Investments<br>i. Renewable Energy Net-Metering Scheme<br>j. Scale-Up Renewable Energy Programme (SREP)<br>k. Mini-Grids and Off-grid Programmes |
| 8 | Renewable Energy Resources & Potential Power Plants | Muhammed Aminu, ECG | a. ECG's Engagement with Developers of RE Projects<br>b. Cost of Potential Projects<br>c. Current RE Plants in Operation<br>d. Planned/Potential Projects<br>e. Timing of Projects<br>f. Challenges for Grid Connected RE Projects (Solar and Wind) |
| 9 | Renewable Energy Resource Potential In Ghana | Frederick Kenneth Appiah, EC | a. Overview of Power Sector<br>b. About the Energy Commission |

| No. | Topic | Presenter | Highlights |
|---|---|---|---|
| | | | c. Renewable Energy Resource Assessment<br>d. State of Planned/Potential Projects<br>e. Regulatory Framework<br>f. Challenges |

## 3.2 Key Issues Raised

The following key issues were raised during the Q&A sessions following the presentations.

***Table 3: Key Issues Raised in Discussions***

| No. | Issues Raised | Response |
|---|---|---|
| 1 | ***MoPet:*** How soon are we going to see real work on the Pwalugu project? | ***VRA:*** Feasibility study on the Pwalugu project is still on-going. The prospects will depend on the outcome of the feasibility studies. The decision to execute the project as well as the project commencement date will be predicated on the report of the feasibility studies |
| 2 | ***MoPet:*** Has VRA considered the possible effect of illegal small scale mining (Galamsey) on the inflows into the Volta lake? | ***VRA:*** We haven't considered the effect of Galamsey. Previous works have shown that the effect of sedimentation is minimal and this is anticipated going forward. |
| 3 | ***NEXANT:***<br>Is the dam accumulating any silt and what is being done to prevent exacerbation of the situation? | ***VRA:*** No silt observed so far |
| 4 | ***GNGC:*** How come the Presentation on small hydropower did not mention Pra? | ***BPA:*** There is potential in Pra as well as the other mini-hydro resources but the focus of additional power should be on other resources. The topography of the potential hydro sites coupled with issues of settlement would make it difficult to construct proper dams aside from run-offs. Consequently, the role of hydropower going forward might be minimal. |
| 5 | ***BPA:*** Has the CSIR assessed the impact of temperature on photovoltaics | ***CSIR:*** No such research so far because the focus of the department has been on hydro.<br><br>***IRRP:*** IRRP will organize a workshop that would focus on effects of climate change on the power sector in general – where hopefully all lingering concerns would be addressed.<br><br>***USAID/AOR:*** It is my understanding that the Pwalugu project was not meant for just power generation but also other related benefits such as irrigation. |
| 6 | ***Japanese Embassy:*** What is the potential effect/impact of maritime border dispute on | ***GNPC:*** Ghana stands to lose a percentage of the TEN fields. It could also delay development of the field. |

| | | |
|---|---|---|
| | the future petroleum supplies? | MoPet: One of two scenarios could occur, either 100% for Ghana or production sharing based on the proportion of the area on both sides. |
| 7 | ***MiDA:*** There was the need to address the coordination of efforts on LNG? | ***GNPC:*** The GNPC has been mandated Aggregator of gas and this has resulted in a lot more effort on that front. In terms of timelines however, it is a lot more complicated. |

# 4 Activities for Day Two

Day two concluded the planned activities for the Supply Options workshop. The sessions were moderated by the COP of the IRRP Project. The presentations for Day Two focussed on the role of coal and nuclear in the power generation plans for Ghana, followed by discussions on the Cost and Performance of Various Resources from a global perspective; Simplified Least Cost of Electricity (LCOE) Analysis; Merits and limitations of LCOE-based analysis; Methods to Analyse Investment Alternatives; and Environmental Impacts, Mitigation and Regulations of power generation.

## 4.1 Opening

The activities for Day Two commenced at 9:00 am with a brief recap of proceedings on Day One by the COP of the IRRP project. He offered participants the opportunity to comment on pending issues before proceeding to the agenda for day.

## 4.2 Highlights of Presentations on Day Two

***Table 4: Highlights of Presentations on Day Two***

| No. | Topic | Name | Highlights |
|---|---|---|---|
| 1 | VRA/Shenzen Energy 700 MW Coal Power Project | Kwaku Wiafe, VRA | a. Project Overview<br>b. Project Status<br>c. Why Coal<br>d. Technology<br>e. Project Economics<br>f. Mitigating Environmental Impacts |
| 2 | Status of Ghana Nuclear Power Programme | Robert B. M. Sogbadji & Nii Kwashie Allotey | a. Nkrumah’s Nuclear Legacy<br>b. Nuclear Power For Electricity At A Glance<br>c. Benefits of Nuclear Energy<br>d. Economic Competiveness of Nuclear Energy<br>e. Ghana’s Current Energy State and Expansion Plan<br>f. Ghana’s Nuclear Journey<br>g. Objectives of the NEPIO (GNPPO) |
| 3 | Cost and Performance of Various Resources (A Global View) | Maria Scheller, ICF | a. Recent International Development Activity |

| No. | Topic | Name | Highlights |
|---|---|---|---|
| | | | b. Comparison of Capital Cost of Supply Technologies<br>• Hydropower<br>• Gas-to-Power<br>• Renewables<br>• Solar<br>• Wind<br>• Nuclear<br>• Coal |
| 4 | Simplified Least Cost of Electricity (**LCOE**) Analysis; Merits and limitations of LCOE-based analysis IRRP | Ananth Chikkatur, COP, IRRP | a. Why develop a simple LCOE model?<br>b. Overview and Output of the LCOE model<br>c. Benefits & Limitations of the model<br>d. Next Steps |
| 5 | Methods to Analyze Investment Alternatives | Maria Scheller, ICF | Various Approaches to Investment Screening:<br>• Levelized Cost of Electricity (LCOE)<br>• Busbar Costs<br>• Levelized Avoided Cost of Energy (LACE)<br>• Differential Revenue Requirement (DRR)<br>• Capacity Expansion and Production Cost Simulation |
| 6 | Environmental Impacts, Mitigation and Regulations – Electric Power Generating Sector | Saeed Foroco, EPA | a. Environmental Regulations<br>b. Type of electric power generating plants<br>c. permitted by EPA<br>d. Environmental Impacts of power generating plants<br>e. EPA Requirements for Pollution Control in the Sector |

## 4.3 Key Issues raised

The following key issues were raised for discussions after the various presentations.

***Table 5: Key Issues raised in Discussions***

| No. | Issues Raised | Response |
|---|---|---|
| 1 | ***BPA:*** This coal project is obviously helpful in development of the nation but the | • ***VRA:*** it is true that Ghana cannot isolate itself from global environmental issues. |

| No. | Issues Raised | Response |
|---|---|---|
| | development should be sustainable. It is therefore essential that associated environmental issues are taken into consideration since environmental issues are also developmental issues. In the light of this, how do Ghana's commitments in the environmental issues interplay with the proposal for a coal power plant? | However the economic as well as other related issues should be comprehensively considered and hopefully the IRRP will help Ghana make an informed decision in that regard. Essentially the issues should be allowed to speak for itself devoid of sentiments.<br>• ***MOP/RE:*** The developed countries i.e. China, Germany, and USA have significant percentages of coal and continue to add more coal plants to grow their economies. In the same vein, it is only fair that Ghana be given same opportunity to grow its economy using cheap power sources such as coal. |
| 2 | ***IRRP:*** Is the environmental mitigation aspect of the project factored into the total cost of the project? | ***VRA:*** No, it is not.<br>***IRRP***: It would be helpful to include such costs in order to compare it more effectively against other options. |

## 4.4 Closing

The AOR for the IRRP Project, Mr. Waqar Haider, who actively participated in the two half-day workshop provided the closing remarks at the end of the sessions. He noted that the workshop was very useful, and he learned quite a bit from the discussions. He thanked all the participants for actively participating the workshop. The workshop was then brought to a successful end at 1pm.

# 5 Evaluation of Workshop

As part of its M&E work, the IRRP project is conducting evaluations for all workshops. Two post workshop evaluations were conducted, separately for Day One and Day Two of the Supply Options workshop.

Of the 51 participants for Day One, 93% either "***Agreed***" or "***Strongly Agreed"*** that the workshop lived up to their expectations, while 7% remained "***Neutral***". Out of the 41 participants for Day two, 100% of participants respectively "***Agreed***" and "***Strongly Agreed***" that the workshop lived up to their expectations.

The full analyses of the evaluations can be found in Figure 3 and Figure 4 of the Annex B.

The following items were recommended for inclusion into future training workshops

- Impact of vehicle emissions on Ghanaian environment compared to power plants cost and implications
- Working session on spreadsheet models, and use of LCOE tool
- Supply Risk
- The place of Ghana's NAMAS in this IRRP project
- A case study of energy mix of developing countries

Other selected comments included:

- Opportunity should be given for the various institutions to get more involved in the IRRP process
- Very impressive workshop. It is my wish that all stakeholders would play effective roles in order to achieve the goals of the IRRP project
- Well organized. I joined later but was good because each section was meaningful
- Well done, ICF

# 6 Conclusion

The Supply Options Workshop was successfully held in November by the IRRP Team. The evaluation from the participants clearly demonstrated that the objectives of the workshop were achieved.

# 7 ANNEX A: Participants

**Table 6: Participants for Day One**

| No. | INSTITUTION | NAME | SEX | DESIGNATION |
|---|---|---|---|---|
| 1 | MoP | Robert Sogbadji | M | Deputy Director-Nuclear |
| 2 | | Solomon Asoalla | M | Chief Director |
| 3 | | Bright Nyalemorda | M | Asst. Project Officer |
| 4 | | John Nuworklo | M | DPSIM |
| 5 | | Wisdom A. Togobo | M | Director |
| 6 | | Solomon Adjetey | M | Deputy Director of Power |
| 7 | MoPet | Lawrence Apaalse | M | Director Petroleum |
| 8 | | Enoch Asare | M | Engineer |
| 9 | | Twum Addo | M | Dep Director HSSE |
| 10 | Energy Commission | Simpson Attieku | M | Program Officer Strategic Planning and Policy |
| 11 | | Doris Agbevivi | F | Energy Planner |
| 12 | | Dr. Nii Darko K. Asante | M | Director, Technical Regulation |
| 13 | | Frederick Ken Appiah | M | Principal Prog. Ofr |
| 14 | | Salifu Addo | M | Principal Programme Officer |
| 15 | | Edwin Tamakloe | M | Statistician |
| 16 | PURC | Nutifafa Fiasorgbor | M | Sr. Reg. Eng |
| 17 | | Samuel Sarpong | M | Executive Secretary |
| 18 | EPA | Esi Nana Nerquaye-Tetteh | F | Head of Department |
| 19 | GNPC | Albert Longdon-Nyewan | M | Lead Eng |
| 20 | | Peter Abrokwa | M | Commercial Officer |
| 21 | GNGC | Cudjoe Sylvester | M | Economic Analyst |

| No. | INSTITUTION | NAME | SEX | DESIGNATION |
|---|---|---|---|---|
| 22 | | Andrew Adu | M | Commercial Manager |
| 23 | VRA | Abdul Wahab | M | Manager, Generation Planning |
| 24 | | Jonathan Walter | M | Engineer |
| 25 | | Kwaku Wiafe | M | Manager |
| 26 | BPA | Jabesh Amissah-Arthur | M | CEO |
| 27 | | Kwadwo Brentuo Owusu | M | Engineer |
| 28 | GRIDCo | Benjamin Ahunu | M | Principal Engineer |
| 29 | | Getrude Opoku | F | Asst. Engineer |
| 30 | ECG | Sylvia Noshie | F | Mgr/Regulation |
| 31 | | M. Aminu | M | Ag.Mgr/Energy Trading |
| 32 | | Abubakar Umar Farouk | M | Asst. Statistical Officer |
| 33 | NEDco | Moses Tawiah | M | Director, Engineering |
| 34 | | Robert Ato Mensah | M | Energy Manager |
| 35 | MiDA | Mawunyo Rubson | M | Dir Generation Projects |
| 36 | | Nana Gyasiwaa-Addo | F | Prog. Engineer |
| 37 | Agence Francaise de Developpement | Jildaz EVIN | M | Senior Project Officer |
| 38 | | Guy Orsot | M | Project Officer |
| 39 | CSIR-WRI | Barnabas Amisigo | M | Snr Res. Scientist |
| 40 | Embassy of Spain in Accra | Mateo Pérez | M | Trade & Technological Advisor Spanish Commercial Office |
| 41 | NEXANT | Syed Hassan Nawab | M | Gas Sector Transaction Advisor |
| 42 | | Anthony Carvalho | M | Power Sector Transaction Advisor |
| 43 | Embassy of Japan in Ghana | Noriaki Sadamoto | M | First Secretary |
| 44 | USAID/GHANA | Waqar Haider | M | Sr. Energy Advisor, Economic Growth Office |
| 45 | USAID IRRP | Ananth Chikkatur | M | Chief of Party |

| No. | INSTITUTION | NAME | SEX | DESIGNATION |
|---|---|---|---|---|
| 46 | | Bernard Tawia Modey | M | Senior Power Expert |
| 47 | | Maxwell Amoah | M | Deputy Chief of Party |
| 48 | | Charles Acquaah | M | M&E Specialist |
| 49 | | Edith Mills Tay | F | Office Manager |
| 50 | | Collins Dadzie | M | Energy Modeler |
| 51 | ICF | Maria Scheller | F | |

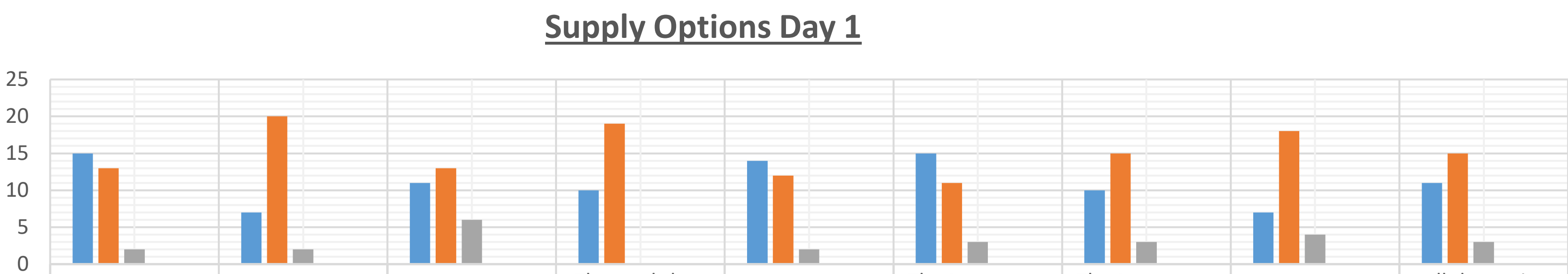
*Table 7: Participants for Day Two*

| No. | INSTITUTION | NAME | SEX | DESIGNATION |
|---|---|---|---|---|
| 1 | MoP | Robert Sogbadji | M | Deputy Director-Nuclear |
| 2 | | Solomon Asoalla | M | Chief Director |
| 3 | | William E. Sam-Appiah | M | Director Gen & Trans |
| 4 | | John Nuworklo | M | DPSIM |
| 5 | | Wisdom A. Togobo | M | Director |
| 6 | | Solomon Adjetey | M | Deputy Director of Power |
| 7 | MoPET | Lawrence Apaalse | M | Director Petroleum |
| 8 | | Enoch Asare | M | Engineer |
| 9 | Energy Commission | Doris Agbevivi | F | Energy Planner |
| 10 | PURC | Nutifafa Fiasorgbor | M | Sr. Reg. Eng |
| 11 | EPA | Saeed Foroco | M | PPO |
| 12 | GNPC | Tetteh Wilson-Tei | M | Corporate Strategy & New Business |
| 13 | | Abigail Agyekum | F | Corporate Strategy & New Business |
| 14 | | Doe Mensah | F | Strategy Officer |
| 15 | GNGC | Cudjoe Sylvester | M | Economic Analyst |
| 16 | VRA | Abdul Wahab | M | Manager, Generation Planning |
| 17 | | Peter Osei-Adjei | M | Petroleum Engineer |
| 18 | | Jonathan Walker | M | Engineer |
| 19 | BPA | Kwadwo Brentuo Owusu | M | Engineer |
| 20 | GRIDCo | Kassim Abubakar | M | Principal Elect Engineer |
| 21 | | Benjamin Ahunu | M | Principal Engineer |
| 22 | | Emmanuel Oduro-Boadu | M | Electrical Engineer |
| 23 | NEDCo | Robert Ato Mensah | M | Energy Manager |
| 24 | MiDA | Mawunyo Rubson | M | Dir Generation Projects |
| 25 | | Nana Gyasiwaa-Addo | F | Prog. Eng |
| 26 | Agence Francaise de Developpement | Guy Orsot | M | Project Officer |
| 27 | CSIR-WRI | Barnabas Amisigo | M | Snr Res. Scientist |
| 28 | NEXANT | Syed Hassan Nawab | M | Gas Sector Transaction Advisor |

| No. | INSTITUTION | NAME | SEX | DESIGNATION |
|---|---|---|---|---|
| 29 | | Anthony Carvalho | M | Power Sector Transaction Advisor |
| 30 | Embassy of Japan in Ghana | Seena Kitami | M | Economic Researcher |
| 31 | | Noriaki Sadamoto | M | First Secretary |
| 32 | USAID/GHANA | Ben Burnes | M | Economic Office |
| 33 | | Waqar Haider | M | Sr. Energy Advisor, Economic Growth Office |
| 34 | USAID IRRP | Ananth Chikkatur | M | Chief of Party |
| 35 | | Bernard Tawia Modey | M | Senior Power Expert |
| 36 | | Maxwell Amoah | M | Deputy Chief of Party |
| 37 | | Maame Tabuah Ankoh | F | RE Specialist |
| 38 | | Charles Acquaah | M | M&E Specialist |
| 39 | | Edith Mills Tay | F | Office Manager |
| 40 | | Collins Dadzie | M | Energy Modeler |
| 41 | ICF | Maria Scheller | F | |

# 8 ANNEX B: Evaluations

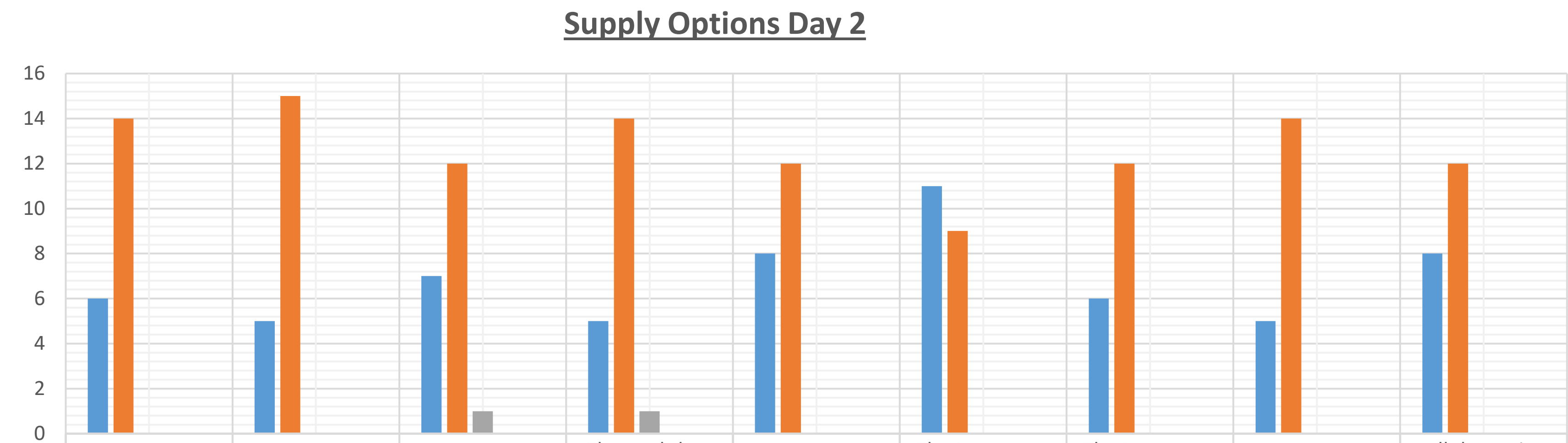
*Figure 3: Analysis of Evaluation for Day One*




| | The workshop objectives were clearly spelt out | The workshop lived up to my expectation | The content was relevant to my job | The workshop was easy to follow and understand | The Presenters were well prepared | The Presenters had adequate knowledge of the subject | The Presenters were able to answer all my questions | The objectives of the workshop were met | All the topics presented were relevant and informative |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Strongly Agree | 15 | 7 | 11 | 10 | 14 | 15 | 10 | 7 | 11 |
| Agree | 13 | 20 | 13 | 19 | 12 | 11 | 15 | 18 | 15 |
| Neutral | 2 | 2 | 6 | 0 | 2 | 3 | 3 | 4 | 3 |
| Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Strongly Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

*Figure 4: Analysis of Evaluation of Day Two*




| | The workshop objectives were clearly spelt out<br>1 | The workshop lived up to my expectation<br>2 | The content was relevant to my job<br>3 | The workshop was easy to follow and understand<br>4 | The Presenters were well prepared<br>5 | The Presenters had adequate knowledge of the subject<br>6 | The Presenters were able to answer all my questions<br>7 | The objectives of the workshop were met<br>8 | All the topics presented were relevant and informative<br>9 |
|---|---|---|---|---|---|---|---|---|---|
| Strongly Agree | 6 | 5 | 7 | 5 | 8 | 11 | 6 | 5 | 8 |
| Agree | 14 | 15 | 12 | 14 | 12 | 9 | 12 | 14 | 12 |
| Neutral | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Strongly Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# F. Transmission Analysis

As part of the IPSMP and the IPM modelling, the IRRP project conducted a series of analysis on the transmission system in Ghana, including the determination of transmission constraints, determination of IPM model regions based on the constraints, the total transfer capability across the constrained zones, and an intra-zonal transmission security analysis. The analyses were reviewed by GRIDCo.

The report below summarizes the work done for the transmission analysis.

USAID
FROM THE AMERICAN PEOPLE

ICF

# Integrated Resource and Resilience Planning (IRRP) Project

## Whitepaper on Transmission Analysis
## Final Report
## November 2018

# Contents

## List of Figures



## List of Tables

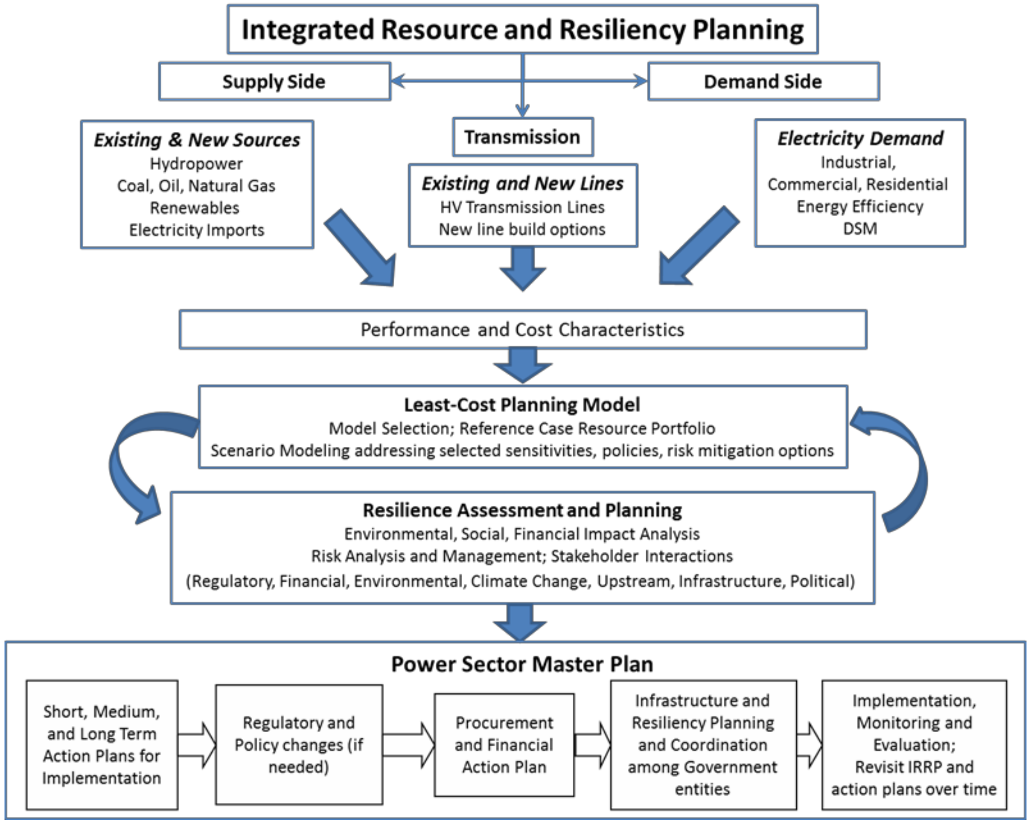
# SECTION 1: TRANSMISSION SYSTEM PLANNING AND ANALYSIS

## I. INTRODUCTION AND OVERVIEW

The Ghana IRRP Project provides technical assistance and capacity building to various agencies in the Ghana power sector to support the: (1) evaluation of all power generation sources (both central-station and distributed resources) simultaneously, (2) consideration of expansion and improvement of the transmission and distribution system, and (3) use of demand-side management (including energy efficiency) that acts as a “source” of energy in long-term planning.

The primary objective of the Ghana IRRP Project is to identify a long-term power sector resource plan that will serve the expected electricity demand over time. The IRRP considers all supply-side resource options, including thermal and renewable energy sources, as well as transmission capability, along with demand-side resources and efficiency opportunities. The resilience of the resource plan is evaluated by understanding how uncertainties, such as climate change, fuels prices and availability, regulatory changes, and other related factors can impact the outcomes of interest (such as cost, CO2 emissions) through scenario analysis. The optimal resource plan resulting from the IRRP process will be a “least-regrets” plan that is expected to be more resilient to changing circumstances and unexpected events as compared to a least-cost plan. Identification of the resource plan provides the foundational elements to support the design of effective mechanisms to enable greater investment in the power sector that is necessary for economic development in Ghana.

**Figure 1: Overview of IRRP Planning Activities**




A strategic Integrated Power System Master Plan (IPSMP) resulting from the IRRP modeling and capacity building will outline implementation plans, regulatory/policy recommendations, procurement plans, and infrastructure planning and coordination guidelines.

It is worth noting that most of the power plants in Ghana are located at three(3) main power enclaves (Akosombo/Kpong, Tema and Aboadze) while consumption is nation-wide even though more than 60% of the load is concentrated in Accra/Tema area alone. The next largest load centre is Kumasi which is far from any generating plant. A robust grid is therefore critical in evacuating power from the various generating plants to the load centres, nation-wide. It is imperative to have a reliable and stable transmission network with adequate capacity to transmit the required amount of power in the face of increasing power demand.

## II. Overview of Ghana Transmission Network

Ghana's transmission network has a backbone of 161 kV transmission lines supplemented by 69 kV lines and two 330 kV line sections. GRIDCo is in the process of developing a set of 330 kV projects that could result in 330 kV replacing 161 kV as the backbone of the system. This would further improve the transfer capability of the system.

The approximately 364 km of 330 kV transmission lines, 4,637 km of 161 kV lines and 133 kM or 69 kV lines connect some 123 transformers at substations in various generation and load centers. These transformers step up voltage for power delivery to other transmission substations or step down the voltage for delivery to distribution substation and subsequently to customers. Ghana also maintains interconnections to its neighbors. In the southwest, the GRIDCo system connects to Cote D'Ivoire via a 74 km, 225 kV transmission tie-line from Prestea to Reviera. To the southeast, a pair of 161 kV circuits from Akosombo to Lome connect the Ghana transmission system to that of Togo. A radial 34.5 kV line also connects the northern part of Ghana's system to load in Togo, from Bawku to Dapong. Lastly a 34.5 kV tie-line from Zebila to Youga link the Ghana and Burkina Faso transmission systems.

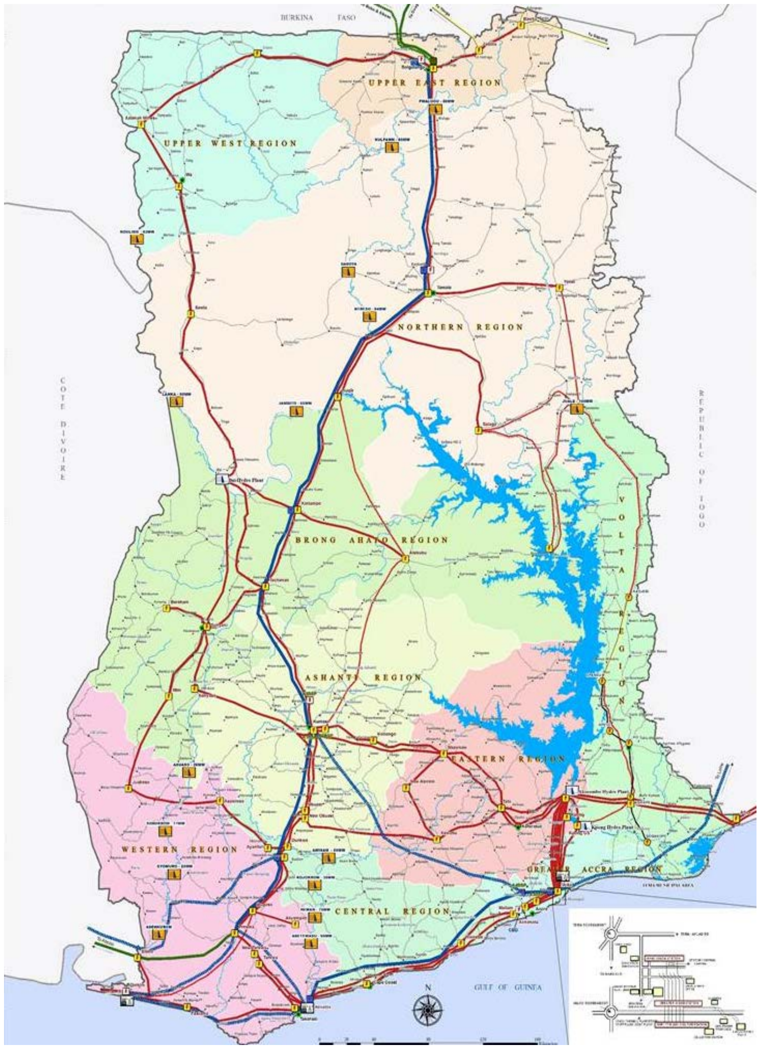
Table 1 summarizes the characteristics of the transmission network, and Figure 2 shows the transmission network.

**Table 1: Ghana Transmission Network Characteristics**

| Item Description | Value |
|---|---|
| Total Length of Transmission Lines | 5,208 km |
| *Length of 330 kV lines* | *364 km* |
| *Length of 225 kV lines* | *74 km* |
| *Length of 161 kV lines* | *4,637 km* |
| *Length of 69 kV lines* | *133 km* |
| Number of Transformers | 123 |
| Total Transformer Capacity | 4,599 MVA |
| Total Capacitor Bank Capacity | 636 MVAr |
| Total SVC Capacity | 40 MVAr |

Source: 2017 Electricity Supply Plan for the Ghana Power System

## Figure 2: Ghana Transmission Network




Source: GRIDCo

# III. Transmission System Reliability Assessment

The transmission network connects generation resources to load centers and facilitates the delivery of power to customers. ICF simulated the operation of the grid under certain expected conditions and determined whether the grid would operate reliably under normal and emergency conditions. Normal conditions, also referred to as system intact, imply that all transmission assets, such as transmission lines and transformers are in service. Emergency or contingency conditions refer to system operations following the loss of one or more transmission assets, although ICF limited the assessment for the Ghana system to the loss of just a single major element at a time. As described in detail in this chapter of the report, ICF conducted a set of 3 studies to assess the reliability of the system. ICF performed Total Transfer Capability (TTC) analysis, Transmission Security Analysis (TSA) and Import/Export Capability studies.

## Transmission System Assumptions

ICF performed the transmission system planning studies for the 2018 and 2020 operational years using power flow cases developed in consultation with GRIDCo. The power flow cases were representative of typical peak load operating conditions in the study years. Peak load conditions are examined during system planning because the power system tends to be most stressed during the peak load period. A system designed to meet peak load needs would also be able to serve customer needs reliably in most of the other hours.

Each power flow case includes existing transmission lines and firmly planned projects expected to be in service by the study year. Some of the major projects recently completed by GRIDCo are the 330 kV Volta to Lome line, the 161 kV Takoradi to Tarkwa line, and the 161 kV Asawinso to Juabeso line. These lines were included in both the 2018 and 2020 power flow cases.

In addition, GRIDCo has several transmission projects under development or construction, which are expected to be completed between 2018 and 2020. The major transmission upgrades are shown in Table 2, and new transmission projects are shown in Table 3. The pending upgrades include rerating of the 161 kV Volta to Achimota double circuit line, the 161 kV Volta to Accra East double circuit line, and the 161 kV Achimota to Accra East double circuit. The Volta to Accra East transmission line is currently one of the major constraints to power delivery in the southeast. The major new transmission projects include the 330 kV backbone project originating at Aboadze, in the south of the country and terminating in Bolgatanga in the north. It will improve transfer capability from southwest through the middle belt of the country to the north.

The transmission system assumptions will be updated during the 2019 IPSMP update to ensure that the current view of system conditions and expected transmission improvements at the time of the update are utilized for the study.

**Table 2: Major Transmission Line Upgrades**

| Item # | Project Description | 2018 Rating (MVA) | 2020 Rating (MVA) |
|---|---|---|---|
| 1 | 161 kV Volta to Achimota Line Circuit 1 | 213 | 488 |
| 2 | 161 kV Volta to Achimota Line Circuit 2 | 213 | 488 |
| 3 | 161 kV Volta to Accra East Line Circuit 1 | 213 | 488 |
| 4 | 161 kV Volta to Accra East Line Circuit 2 | 213 | 488 |
| 5 | 161 kV Achimota to Accra East Line Circuit 1 | 213 | 488 |
| 6 | 161 kV Achimota to Accra East Line Circuit 2 | 213 | 488 |
| 7 | 161 kV Asogli to Collector Line Circuit 1 | 324 | 644 |
| 8 | 161 kV Asogli to Collector Line Circuit 2 | 324 | 644 |
| 9 | 161 kV Smelter II to Collector Line Circuit 1 | 324 | 644 |
| 10 | 161 kV Smelter II to Collector Line Circuit 2 | 324 | 644 |

**Table 3: Major Transmission Line Additions**

| Item # | Project Description | Rating (MVA) | In Service Year |
|---|---|---|---|
| 1 | 161 kV Juabeso to Mim Line | 170 | 2018 |
| 2 | 330 kV Aboadze to Dunkwa Line Circuit 1 | 1,000 | 2018 |
| 3 | 330 kV Aboadze to Dunkwa Line Circuit 2 | 1,000 | 2018 |
| 4 | 330 kV Dunkwa to Anwomaso Line | 1,000 | 2018 |
| 5 | 330 kV Anwomaso to Kintampo Line | 1,000 | 2020 |
| 6 | 330 kV Kintampo to Tamale Line | 1,000 | 2020 |
| 7 | 330 kV Tamale to Bolgatanga Line | 1,000 | 2020 |
| 8 | 225 kV Bolgatanga to Ouagadougou Line | 1,000 | 2020 |

## TRANSMISSION PLANNING CRITERIA

Electric transmission equipment are designed to operate within certain limits driven by the physical properties of the equipment and the characteristics of the network. Exceeding these limits can result in inefficient operation, damage to equipment, system failure and danger to personnel. To ensure the grid operates safely and reliably, planner specify criteria within which equipment should operate.

GRIDCo's planning criteria for transmission lines requires that lines operate within their thermal ratings under normal operating conditions. Under contingency conditions they can be operated up to 110% of the normal rating for a relatively short period to enable operators adjust the system and prepare for the next emergency. Exceeding the limits can cause the lines to overheat and sag excessively. This poses safety problems in the event the line comes into contact with vegetation or other items in or close to the rights of way. Overheating can also cause the line to anneal, which would change its metallic properties and affect its performance. In a well-designed system protective equipment will take a line out of service if it exceeds specified limits in order to avoid damage to the line. This could overload other lines that remain in service and lead to cascading outages and a blackout. It is therefore important to ensure that lines will operate within design limits.

Transformers in the GRIDCo system also operate up to 100% of their nominal rating under normal conditions, and up to 120% of the rating under contingency conditions.

Substations are also expected to operate with specific limits to maintain system reliability. Within the GRIDCo network substations are expected to operate within a 5% band of the nominal voltage level under normal conditions, and within a 10% band under contingency conditions. Therefore under normal conditions voltages should remain within 95% and 105% of the nominal rating, also expressed as 0.95 per unit (p.u.) and 1.05 p.u. For a 161 kV system the range would be 153 kV and 169 kV. Excessively low voltages can result in system collapse and blackout.

For this study ICF used reliability criteria consistent with GRIDCo's planning criteria. This is summarized in Table 4.

**Table 4: Transmission Planning Criteria**

| Asset/Equipment | Condition | Low Limit | High Limit |
|---|---|---|---|
| Transmission Lines | Normal | N/A | 100% of Nominal Rating |
| Transmission Lines | Contingency | N/A | 110% of Nominal Rating |
| Transformers | Normal | N/A | 100% of Nominal Rating |
| Transformers | Contingency | N/A | 120% of Nominal Rating |
| Substation (Voltage) | Normal | 0.95 p.u. | 1.05 p.u. |
| Substation (Voltage) | Contingency | 0.90 p.u. | 1.10 p.u. |

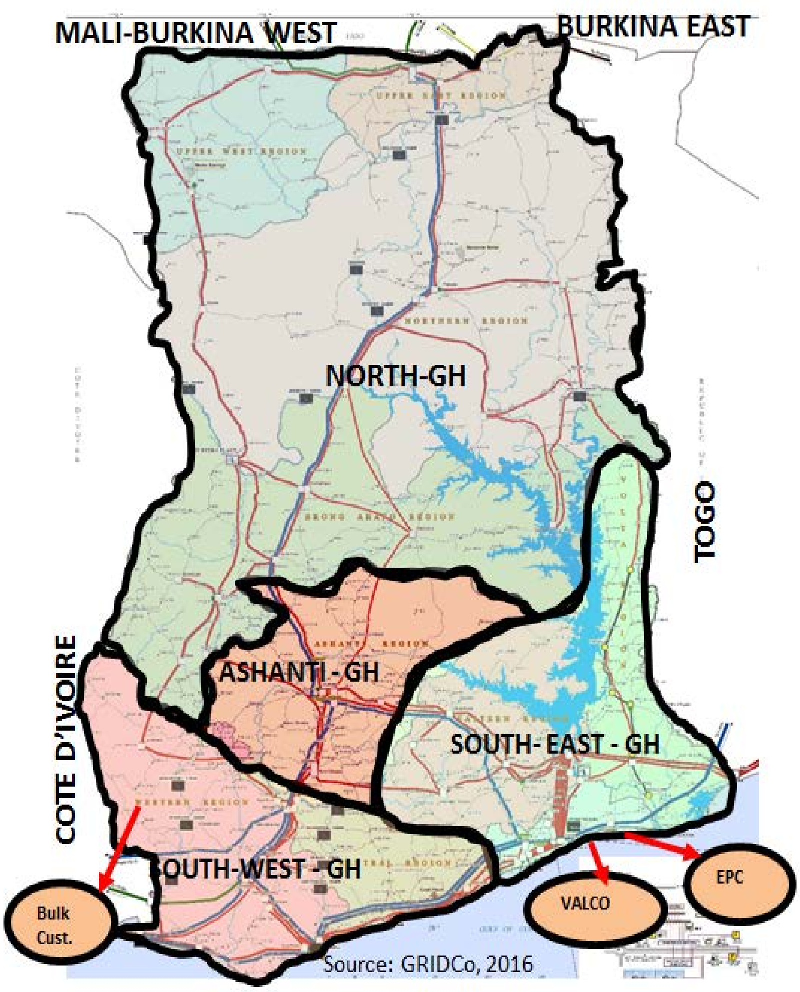
### TRANSFER CAPABILITY ASSESSMENT

As discussed, the properties of a transmission line determine the amount of power that it can transfer reliably. There are therefore limits to the amount of power that can be transferred from one area to another within the electric system. This limit is referred to as the Total Transfer Capability (TTC). The TTC is a measure of the adequacy of the transmission system. It determines the amount of power that can be delivered to or from an area such as a generation pocket or load center without violating reliability limits. If the demand in an area exceeds the TTC for that area, demand might be curtailed to maintain reliability.

To assess the ability of the Ghana electric transmission grid to deliver power from generation resources to customers, ICF divided the transmission network into zones and calculated the TTCs between zones that were directly connected by the transmission network. ICF assessed the reliability of the transmission network by comparing the demand in each zone to the available transfer capability. Each zone comprised a set of electrically contiguous substation selected to minimize transmission congestion with the zone. This is important because the analysis assumes that power delivered into the zone can flow unimpeded to any substation within the zone. The transmission lines connecting a pair of zones is referred to as an interface. Transfer capabilities were calculated across the interfaces.

As shown in Figure 3, the Ghana system was divided into four zones, Ashanti, North, Southeast, and Southwest. The major substations and load centers in each zone are also shown in the figure. For example, the Ashanti zone comprises six substations in combination – Ahafo, Anwomaso, Konongo, Kumasi, New Obuasi, and Obuasi.

**Figure 3: Ghana Bulk Electric System Zonal Configuration**




Source: GRIDCo and ICF

| Zone | Substations |
|---|---|
| South-West | Bogoso, Wexford, Dunkwa, Ayamfuri, Asawinso, Juabeso, Winneba, Cape Coast, Aboadze, Tarkwa, New Tarkwa, Essiama, Effasu, Prestea |
| South-East | Akosombo, Kpong, Kpone, Volta, Smelter, Achimota, Mallam, Accra East, Asogli, Karpower, AKSA, Asiekpe, Ho, Kpando, Kadjebi, Sogakope, Aflao, Tafo, Akwatia, Nkawkaw |
| Ashanti | Ahafo, Anwomaso, Konongo, Kumasi, New Obuasi, Obuasi, |
| North | Sunyani, Techiman, Kintampo, Tamale, Buipe, Yendi, Bolgatanga, Zebila, Navrongo, Tumu, Sawla, Wa, Bui, Mim |

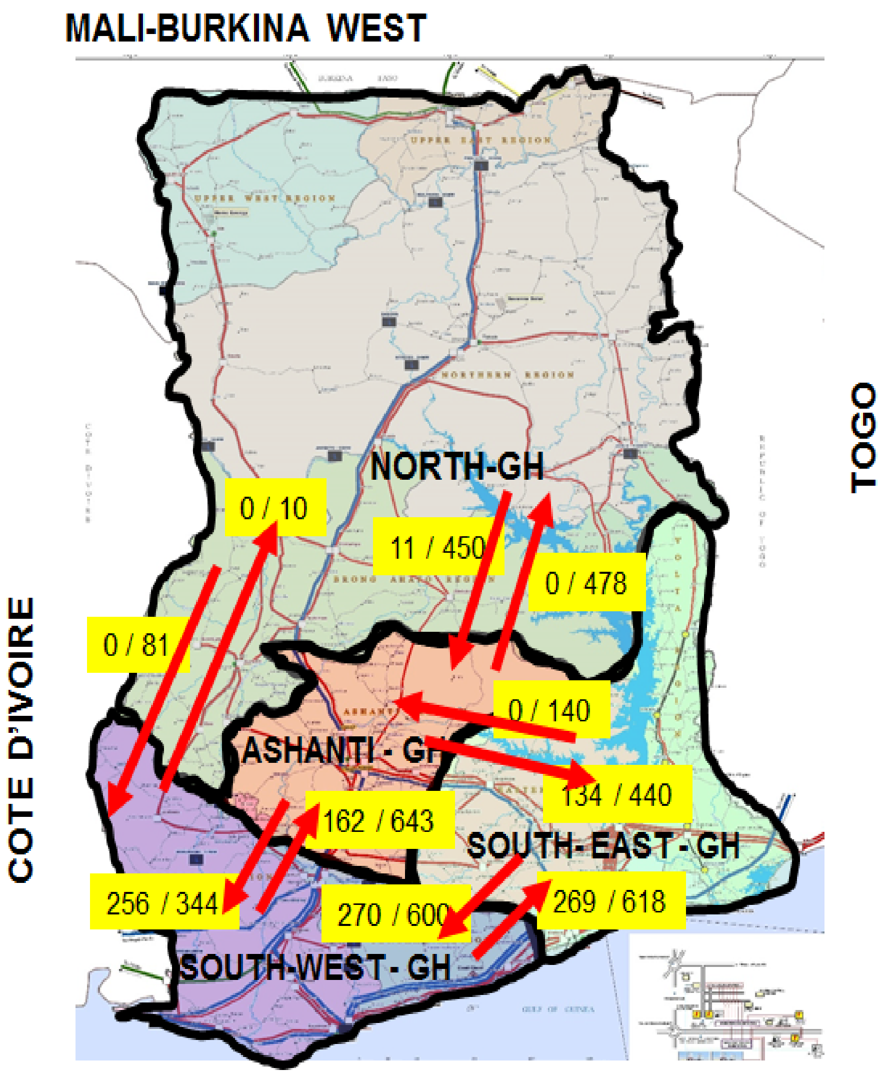
Table 5 shows the interfaces between zones in the power system. For example, the Ashanti-North interface comprises the 161 kV Kumasi – Techiman line, the 161 kV Kumasi-Kenyase line, and the 161 kV Obuasi-Kenyase line. The capacity of the interface is expanded in 2020 with the addition of the new 330 kV Anwomaso – Kintampo line.

**Table 5: Ghana Bulk Power System Zonal Interface Definitions**

| Interface Description | Component Lines (2018) | Component Lines (2020) |
|---|---|---|
| South West – South East | 161 kV Mallam – Cape Coast line | 161 kV Mallam – Cape Coast line |
| | 161 kV Mallam – Winneba line | 161 kV Mallam – Winneba line |
| | 330 kV Aboadze – Volta line | 330 kV Aboadze – Volta line |
| South West - North | 161 kV Mim – Juabeso line | 161 kV Mim – Juabeso line |
| South West - Ashanti | 330 kV Dunkwa - Anwomaso | 330 kV Dunkwa - Anwomaso |
| | 161 kV Dunkwa – New Obuasi | 161 kV Dunkwa – New Obuasi |
| | 161 kV Prestea - Obuasi | 161 kV Prestea - Obuasi |
| South East - Ashanti | 161 kV Nkawkaw - Konongo | 161 kV Nkawkaw - Konongo |
| | 161 kV Nkawkaw - Anwomaso | 161 kV Nkawkaw - Anwomaso |
| | 161 kV Akwatia – New Obuasi | 161 kV Akwatia – New Obuasi |
| Ashanti - North | 161 kV Kumasi - Techiman | 161 kV Kumasi - Techiman |
| | 161 kV Kumasi - Kenyase | 161 kV Kumasi - Kenyase |
| | 161 kV Obuasi - Kenyase | 161 kV Obuasi - Kenyase |
| | | 330 kV Anwomaso - Kintampo |

ICF calculated firm and non-firm TTCs for each interface. Firm TTC refers to power that can be transferred with a high level of reliability. It is the power that can be transferred without exceeding reliability limits even with the outage of a major transmission line or transformer. Firm TTC is therefore used for capacity transfers. Non-Firm TTC is the transfer capability with all transmission elements in service. Non-Firm TTC is almost always higher than Firm TTC, but it has a lower level of reliability because it can be curtailed in the event of an outage of a major transmission line or transformer. Non-Firm TTCs provide incremental capability over the firm limit, which can be used for energy transfers. Figure 4 shows the Firm and Non-Firm TTCs calculated for Ghana's bulk power system for 2018, and Figure 5 shows the values for 2020 and subsequent years.

**Figure 4: Ghana Bulk Power System Transfer Capability – 2018**

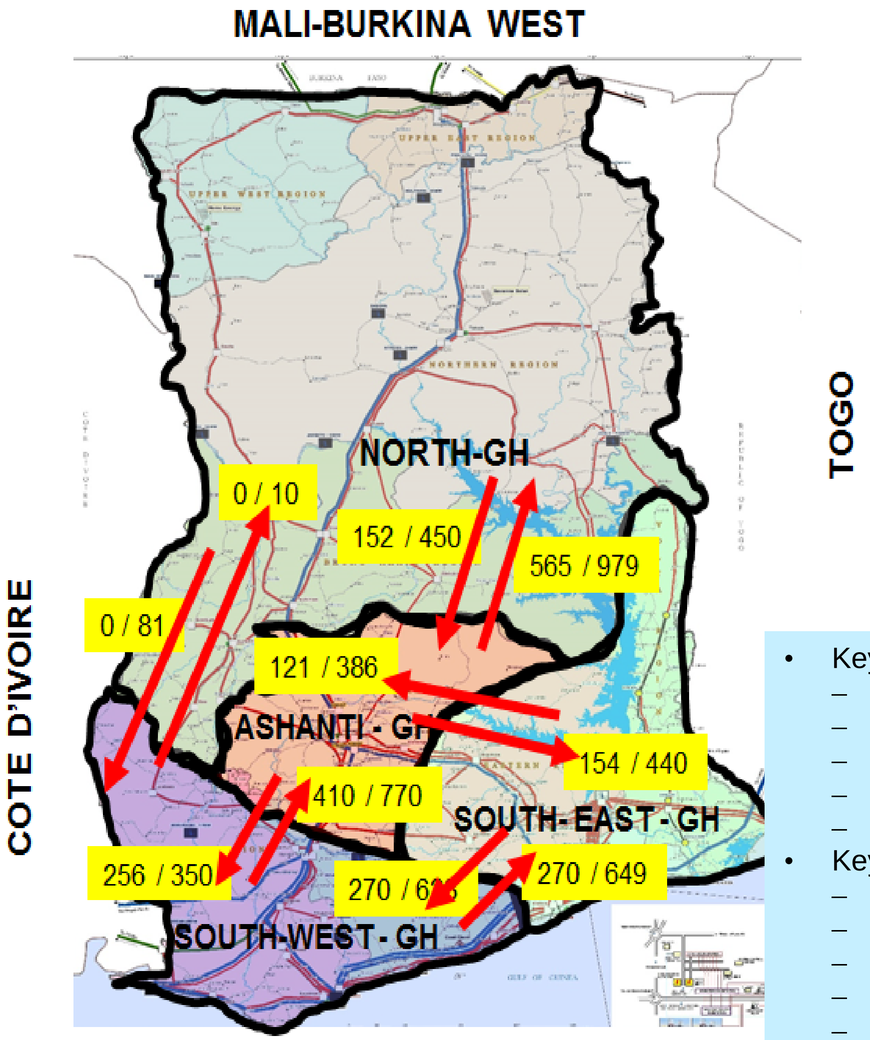



The constrained elements and corresponding contingencies that result in the transfer capability limits are shown in Table 6 and Table 7 for 2018 and 2020, respectively. For example, in 2018 the South-West to Ashanti interface is limited to a firm transfer capability of 162 MW. This is due to the potential overload of the 161 kV Cape Coast to Aboadze transmission line for the outage of the 330 kV Accra 4 BSP to Aboadze line. Non-firm transfers are limited to 643 MW by the 330/161 kV transformer at Aboadze. This means when the bulk power system is operating with all transmission lines and transformers in service, up to 643 MW of power can be transferred from the Southwest zone to the Ashanti zone. In the event of an outage, the transfer capability could be as low as 162 MW. Under contingency conditions there is a risk that the capability to deliver generation from the Southwest zone to Ashanti and the North will be insufficient to meet demand in those zones. This could result in demand curtailment to maintain reliability if delivery capability from the Southeast cannot make up the difference.

**Table 6: Ghana Bulk Power System Transfer Capability and Limiting Constraints and Contingencies – 2018**

| Interface | TTC (MW) | TTC Priority | Limiting Constraints | Limiting Contingency |
|---|---|---|---|---|
| **South West – South East** | 269 | Firm | 161 kV Dunkwa – New Obuasi | 330 kV Dunkwa - Anwomaso |
| | 618 | Non-Firm | 161/330 Aboadze Transformer | None |
| **South East – South West** | 270 | Firm | 161 kV K7FZ | 330 kV Volta - Asogli |
| | 600 | Non-Firm | 161 kV Winneba - Mallam | None |
| **South West - Ashanti** | 162 | Firm | 161 kV Cape Coast – Aboadze T3 | 330 kV A4BSP - Aboadze |
| | 643 | Non-Firm | 161/330 Aboadze Transformer | None |
| **South East – Ashanti** | 0 | Firm | 161 kV Dunkwa – New Obuasi | 161 kV Prestea - Obuasi |
| | 139 | Non-Firm | 161 kV Dunkwa – New Obuasi | None |
| **South West – North** | 0 | Firm | 161 kV Cape Coast – Aboadze T3 | 330 kV A4BSP - Aboadze |
| | 10 | Non-Firm | 161/330 Aboadze Transformer | None |
| **North – South West** | 0 | Firm | 161 kV Techiman - Sunyani | 161 kV Sunyani - Bui |
| | 81 | Non-Firm | 161 kV Kumasi - Techiman | None |
| **North – Ashanti** | 10 | Firm | 161 kV Dunkwa – New Obuasi | 330 kV Anwomaso Phase Shift Transformer |
| | 450 | Non-Firm | 161 kV Kumasi - Techiman | None |
| **Ashanti - North** | 0 | Firm | 161 kV Dunkwa – New Obuasi | 330 kV Dunkwa - Anwomaso |
| | 477 | Non-Firm | 161 kV Kumasi - Anwomaso | None |
| **Ashanti – South East** | 133 | Firm | 161 kV Cape Coast – Mallam | 330 kV A4BSP – Aboadze |
| | 440 | Non-Firm | 161 kV Nkawkaw - Konongo | None |
| **Ashanti – South West** | 256 | Firm | 161 kV Dunkwa – New Obuasi | 161 kV Kumasi – New Obuasi |
| | 344 | Non-Frim | 161 kV Dunkwa – New Obuasi | None |

### Figure 5:Ghana Bulk Power System Transfer Capability – 2020




- Key Constraints
  - 161 kV Dunkwa – New Obuasi Line
  - 330/161 kV Dunkwa Transformer
  - 161 kV Akosombo – Tafo Line
  - 161 kV Nkawkaw – Tafo Line
  - 161 kV Kintampo Transformer
- Key Contingencies
  - 330 kV Dunkwa – Anwomaso Line
  - 330 kV Tamale – Kintampo Line
  - 161 kV Kumasi – New Obuasi
  - 161 kV Tarkwa – Aboadze
  - 161 kV Kumasi – Techiman

### Table 7: Ghana Bulk Power System Transfer Capability and Limiting Constrains and Contingencies – 2020

| Interface | TTC (MW) | TTC Priority | Limiting Constraints | Limiting Contingency |
|---|---|---|---|---|
| **South West – South East** | 270 | Firm | 161 kV Takoradi - Tarkwa | 161 kV Tarkwa - Aboadze |
| | 648 | Non-Firm | 161 kV Cape Coast – Aboadze T3 | None |
| **South East – South West** | 270 | Firm | 161 kV Akosombo – Kpong GS | 161 kV Volta - KTPP |
| | 622 | Non-Firm | 161/330 Volta Transformer | None |

| | | | | |
|---|---|---|---|---|
| **South West - Ashanti** | 410 | Firm | 161 kV Akosombo - Tafo | 330 kV Dunkwa - Anwomaso |
| | 770 | Non-Firm | 161/330 Dunkwa Transformer | None |
| **South East – Ashanti** | 121 | Firm | 161/330 Dunkwa Transformer | 330 kV Dunkwa - Anwomaso |
| | 385 | Non-Firm | 161 kV Nkawkaw - Tafo | None |
| **South West – North** | 0 | Firm | 161/330 Dunkwa Transformer | 330 kV Dunkwa - Anwomaso |
| | 10 | Non-Firm | 161/330 Kintampo Transformer | None |
| **North – South West** | 0 | Firm | 161/330 Kintampo | 161 kV Kumasi - Techiman |
| | 81 | Non-Firm | 161/330 Kintampo | None |
| **North – Ashanti** | 151 | Firm | 161 kV Dunkwa – New Obuasi | 330 kV Anwomaso Phase Shift Transformer |
| | 449 | Non-Firm | 161/330 Kintampo | None |
| **Ashanti - North** | 564 | Firm | 161/330 Kintampo | 330 kV Tamale - Kintampo |
| | 978 | Non-Firm | 161 kV Obuasi - Kenyase | None |
| **Ashanti – South East** | 154 | Firm | 161 kV Dunkwa – New Obuasi | 161 kV Kumasi – New Obuasi |
| | 440 | Non-Firm | 161 kV Nkawkaw - Konongo | None |
| **Ashanti – South West** | 256 | Firm | 161 kV Dunkwa – New Obuasi | 161 kV Kumasi – New Obuasi |
| | 350 | Non-Frim | 161 kV Dunkwa – New Obuasi | None |

## TRANSFER CAPABILITIES FOR GENERATION AND LOAD CENTERS

In addition to calculating the TTCs between zones, ICF calculated the simultaneous export limits for the generation centers and the simultaneous import limits for major load centers. This was to ensure that there was sufficient transmission capacity both to evacuate the generation from the supply regions and also to deliver it into the major load centers. If the simultaneous export limit from a generation pocket is lower than the net generation capacity, some generation would be bottled up and unavailable to serve customers. Similarly, if the simultaneous import limit into a load center is lower than the net demand in the load center, then the demand might be curtailed in some hours.

For this assessment ICF focused on the major generation centers in the southeast and southwest. The generation in the southeast is made up of generators in Akosombo, Akuse and Tema. The southwest is made up of generators in Aboadze. The assessment of import limits focused on the largest load centers in Ghana, Accra and Kumasi. Unlike cities such as Takoradi and Tema, that have access to internal generation, Accra and Kumasi load centers have no local generation and depend entirely on imports to meet demand. Both cities therefore have a critical need for power imports.

The analysis was performed for the 2018 operating year and the following scenarios were examined:

- **Southeast Export Capability:** In this scenario, generating plants in Akosombo, Kpong and Tema were considered as a single generation pocket. Power export from this generation pocket to the rest of the GRIDCo system was evaluated and the limiting contingency and constraint to the ability to export power identified.
- **Southwest Export Capability:** In this scenario, generating plants in Aboadze were considered as a single generation pocket. Power export from this generation pocket to the rest of the GRIDCo system was evaluated and the limiting contingency and constraint to ability to export power identified.
- **Accra Import Capability:** In this scenario, power transfer from the rest of the system to serve Accra load pocket was evaluated.
- **Kumasi Import Capability:** In this scenario, power transfer from the rest of the system to serve Kumasi load pocket was evaluated.

The generators in the southeast zone and the southwest zone are listed in Table 8 and Table 9, respectively.

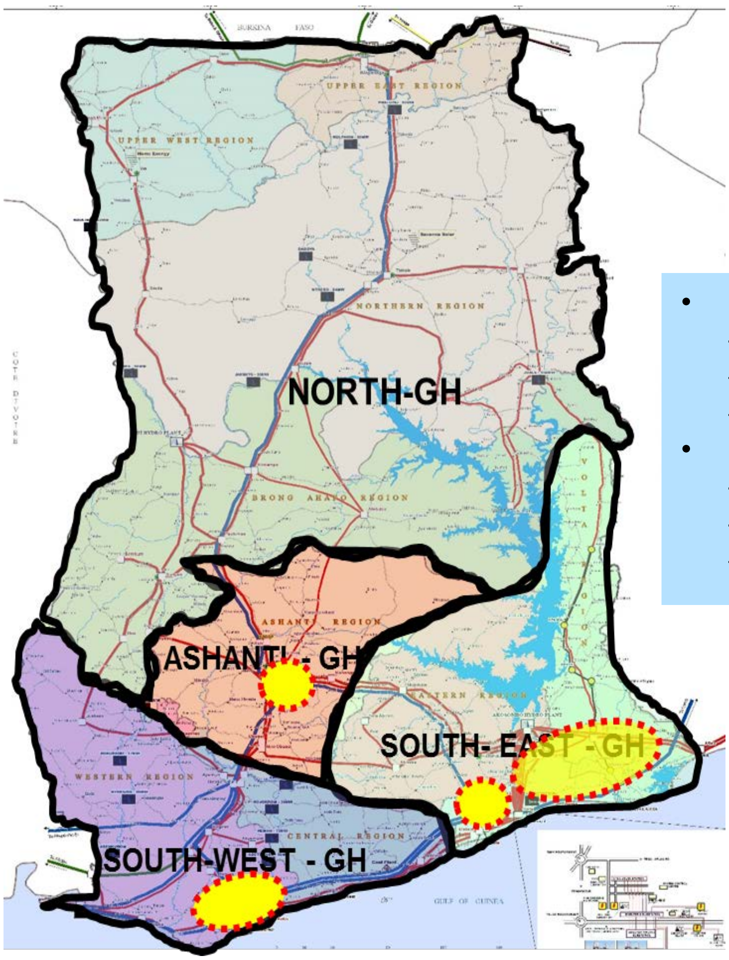
**Table 8: Resources in Southeast Generation Zone**

| Generator Name | Generation Center | Capacity (MW) |
|---|---|---|
| Akosombo Power Plant | Southeast (Akosombo/Kpong) | 1,020 |
| Kpong Power Plant | Southeast (Akosombo/Kpong | 160 |
| TT1PP | Southeast (Tema) | 126 |
| TT2PP | Southeast (Tema) | 49.5 |
| MRP | Southeast (Tema) | 80 |
| KTPP | Southeast (Tema) | 220 |
| SAPP | Southeast (Tema) | 200 |
| SAPP 2 | Southeast (Tema) | 360 |
| CENIT | Southeast (Tema) | 126 |
| KarPower | Southeast (Tema) | 225 |
| AKSA | Southeast (Tema) | 370 |
| | **Total** | **2,936.5** |

**Table 9: Resources in Southwest Generation Zone**

| Generator Name | Generation Center | Capacity (MW) |
|---|---|---|
| TAPCO | Southwest | 330 |
| TICO | Southwest | 340 |
| Ameri | Southwest | 250 |
| T3 | Southwest | 132 |
| **Total** | | **1,052** |

Figure 6: Key Constraints and Location of Generation and Load Centers




- Key Constraints
  - 161 kV Volta – Accra East Circuit 1 or 2
  - 161 kV Dunkwa – New Obuasi Line
  - 161 kV Cape Coast – Aboadze Line
- Key Contingencies
  - 161 kV Volta – Accra East Circuit 1 or 2
  - 330 kV Dunkwa – Anwomaso Line
  - 330 kV Accra 4BSP – Aboadze Line

The results of the export capability assessment from the Akosombo/Kpong/Tema generation center to the rest of the GRIDCo system is shown in Table 10. The firm and non-firm export capabilities are 451 MW and 1,099 MW respectively. In both cases the transfers are limited by the double circuit 161 kV Volta to Accra East line. Firm exports are limited to 451 MW by one circuit of the 161 kV Volta to Accra East double circuit line, under the contingency outage of the other circuit. Non-firm exports are limited to 1,099 MW by any one circuit of the double circuit line. Therefore, under normal operating conditions, up to 1,099 MW, or 43% of the total generation in the southeast generation center can be exported to meet customer demand without violating reliability criteria. However, under contingency conditions, such as the outage of one circuit of the Volta to Accra East line, net generation output from the region will have to be curtailed to 451 MW to avoid overloading any of the lines.

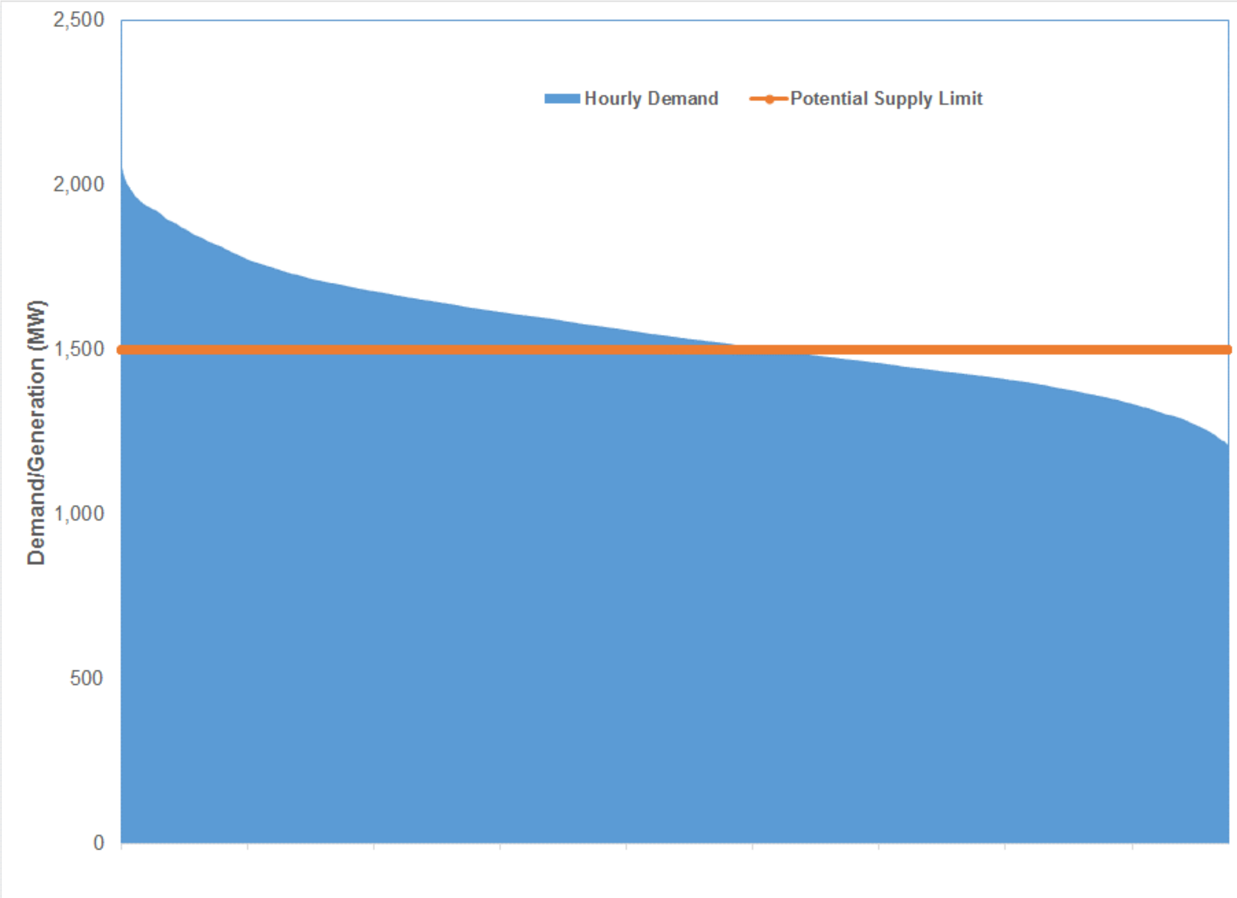
**Table 10: Firm and Non-Firm Export Capability from Akosombo/Kpong/Tema Generation Pocket – 2018**

| TTC (MW) | TTC Priority | Limiting Constraint | Limiting Contingency |
|---|---|---|---|
| 451 | Firm | 161 kV Volta to Accra East Circuit 1 | 161 kV Volta to Accra East Circuit 2 |
| 1,099 | Non-Firm | 161 kV Volta to Accra East Circuit 1 | None |

This means that under certain contingency conditions, GRIDCo would have to rely heavily on generation from the South-West to meet customer demand. Even with full dispatch from the South-West, some demand might have to be curtailed to maintain system reliability. If all generation is assumed to operate at their maximum capacity, the total generation from the South-West would be 1,052 MW (see Table 9). The total generation available from the south of the country would be 1,503 MW. The actual amount available would be less, because operational limits or security issues would likely prevent maximum dispatch from the Southwest. The implications of high South-West dispatch on the grid is described in the Transmission Security Analysis section. ICF's analysis shows that several transmission line and substation voltage constraints could limit the dispatch from the South-West.

Figure 7 shows the 2016 load duration curve for the GRIDCo system as a proxy for 2018 system conditions. The load duration curve is the hourly demand arranged from highest to lowest, irrespective of the hour in which it occurred. The potential firm supply limit of 1,503 from the south, due to the South-East generation deliverability constraints, is also shown in relation to the load duration curve. Generation dispatch of 1,503 MW is lower than the GRIDCo demand in approximately 5,126 hours, or 58% of the time. Therefore, there is a real risk that under certain contingency conditions load would have to be curtailed due to insufficient generation. The load curtailment could be higher than 570 MW if it occurred during the peak demand period.

**Figure 7: 2016 Load Duration Curve with Supply Limit Due to Southeast Generation Deliverability Constraints**




Further, ICF evaluated the transfer capability from the Tema generation pocket and the Akosombo/Kpong generation pocket separately to ensure that additional constraints would not limit dispatch from the sub zones even if the joint Southwest constraints are addressed. The 2018 transfer capabilities out of the Tema generation pocket and the Akosombo/Kpong generation pocket are shown in Table 11 and Table 12, respectively. Firm power transfers out of the Tema generation pocket are limited to only 195 MW by the 161 kV Volta to Accra East Line Circuit 1, for the outage of the second circuit of the 161 kV Volta to Accra East Line. This is severely limiting given the availability of over 1,700 MW of generation capacity in the Tema generation pocket. GRIDCo's proposed upgrade of the 161 kV Volta to Accra East Line from 213 MVA to 488 MVA could potentially increase the transfer capability to 1,116 MW. This will be a significant improvement, and therefore the upgrade should be a priority. However, it increases the transfer capability to just below 65% of the available generation, therefore additional improvements might be required to enable GRIDCo to utilize generation in the Tema area to meet capacity needs.

Non-Firm transfer capability out of the Tema generation pocket is 865 MW in 2018. This is also limited by the 161 kV Volta to Accra East Line Circuit 1. The upgrade of the line could potentially increase the Non-Firm transfer capability to 1,322, or approximately 75% of the available generation capacity in the Tema area. This means that with all lines in service, some generation in the Tema area would not be available for exports to the rest of the system. Additional system improvement implemented to increase the Firm capability would likely improve the Non-Firm capability as well.

**Table 11: Firm and Non-Firm Export Capability from Tema Generation Pocket – 2018**

| TTC (MW) | TTC Priority | Limiting Constraint | Limiting Contingency |
|---|---|---|---|
| 195 | Firm | 161 kV Volta to Accra East Circuit 1 | 161 kV Volta to Accra East Circuit 2 |
| 865 | Non-Firm | 161 kV Volta to Accra East Circuit 1 | None |

The Firm and Non-Firm transfer capabilities out of the Akosombo/Kpong generation pocket are 1,053 MW and 1,457 MW, respectively. Both are also limited by the 161 kV Volta to Accra East Line Circuit 1. The Firm TTC represents approximately 90% of the total generation capacity of 1,180 MW available in the generation pocket, while the Non-Firm TTC exceeds the available generation capacity. GRIDCo's planned upgrade of the 161 kV Volta to Accra East Line could potentially increase the Firm TTC to 1,155 MW or approximately 98% of the available capacity.

**Table 12: Firm and Non-Firm Export Capability from Akosombo/Kpong Generation Pocket – 2018**

| TTC (MW) | TTC Priority | Limiting Constraint | Limiting Contingency |
|---|---|---|---|
| 1,053 | Firm | 161 kV Volta to Accra East Circuit 1 | 330 kV A4BSP to Volta Line |
| 1,457 | Non-Firm | 161 kV Volta to Accra East Circuit 1 | None |

Table 13 shows the export capability from the Aboadze generation pocket to the rest of the GRIDCo system. The 161 kV Cape Coast to Aboadze line limits firm exports to 887 MW under the contingency outage of the 330 kV Accra 4BSP to Aboadze line. Under normal operating conditions, the 161 kV Cape Coast to Aboadze line limits non-firm exports to 1,160 MW. Therefore, the total of 1,052 MW of internal generation in the South-West can be exported to meet consumer load under normal conditions. Under a contingency outage of the 330 kV Accra 4BSP to Aboadze line, exports would have to be curtailed to 887 MW, or approximately 84% of the total generation capacity.

The South-West generation constraint is less limiting than that of the South-East. Almost all of the net generation capacity can be dispatched, even under contingency conditions.

**Table 13: Firm and Non-Firm Export Capability from Aboadze Generation Pocket – 2018**

| TTC (MW) | TTC Priority | Limiting Constraint | Limiting Contingency |
|---|---|---|---|
| 887 | Firm | 161 kV Cape Coast to Aboadze line | 330 kV Accra 4BSP to Aboadze line |
| 1,160 | Non-Firm | 161 kV Cape Coast to Aboadze line | None |

Table 14 shows the import capability into the Accra load center under normal and contingency conditions. Firm imports are limited to 775 MW by the 161 kV Cape Coast to Aboadze line under the contingency outage of the 330 kV Accra 4BSP to Aboadze line. The non-firm import capability is 1,244 MW, limited by the 161 kV Volta to Accra East Circuit 2. The year-to-date peak demand in Accra is approximately 630 MW.[1] Unless the annual peak is significantly higher, the bulk power system will be capable of delivering adequate power to the Accra zone on a firm basis.

**Table 14: Firm and Non-Firm TTC for Import into Accra – 2018**

| TTC (MW) | TTC Priority | Limiting Constraint | Limiting Contingency |
|---|---|---|---|
| 775 | Firm | 161 kV Cape Coast to Aboadze line | 330 kV Accra 4BSP to Aboadze line |
| 1,244 | Non-Firm | 161 kV Volta to Accra East Circuit 2 | None |

Firm and non-firm import capability into the Kumasi load center are shown in Table 15. The firm import capability is 274 MW, which is almost the same as the peak demand of 240 MW in January 2018. The non-firm import capability is 1,243 MW. The firm imports are limited by the 161 kV Dunkwa to New Obuasi line for the contingency outage of the 330 kV Dunkwa to Anwomaso line. Non-firm imports are also limited by the 161 kV Dunkwa to New Obuasi line, but under normal conditions.

[1] As at February 5, 2018

**Table 15: Firm and Non-Firm TTC for Import into Kumasi – 2018**

| TTC (MW) | TTC Priority | Limiting Constraint | Limiting Contingency |
|---|---|---|---|
| 274 | Firm | 161 kV Dunkwa to New Obuasi Line | 330 kV Dunkwa to Anwomaso Line |
| 1,243 | Non-Firm | 161 kV Dunkwa to New Obuasi Line | None |

### TRANSMISSION SECURITY ANALYSIS

Transmission Security Analysis (TSA) assesses the ability of the power system to continue operating following the loss of major elements such as transmission lines and transformers. ICF examined the operation of the Ghana bulk power system during a representative peak period in 2018, and determined if reliability criteria violations would occur under contingency conditions.

ICF performed power flow and contingency analysis of the GRIDCo transmission system to determine if the system would operate reliably under expected peak load conditions. ICF conducted a transmission security analysis and assessed the performance of the network under normal (N-0) and contingency (N-1) conditions. The system was monitored for reliability violations such as line overloads and extreme (high or low) substation violations. Normal conditions assume all network elements are in operation. Under contingency conditions one transmission element is assumed to be out of service.

Power flow on bulk power transmission lines and transformers vary with generation dispatch patterns. Reliability criteria violations might also depend on the dispatch pattern and subsequent line flows. For example, a scenario with higher net dispatch from the southeast generation centers is likely to have higher loading on the Southeast to Ashanti interface, and more likely to overload the lines within the interface than a scenario with lower dispatch from the southeast. ICF modeled several dispatch conditions in order to assess the potential violations that could occur under the full range of dispatch conditions within the Ghana bulk power system. The conditions examined were:

- Scenario 1: Equal dispatch from southeast and southwest generation centers. This assessed operating conditions assuming neither southeast nor southwest interfaces were stressed.
- Scenario 2: Higher dispatch from southeast – case 1. This scenario stressed the southwest interfaces, but partial relief was provided by resources in the southwest.
- Scenario 3: Higher dispatch from southeast – case 2. This scenario had even higher dispatch from the southeast, relative to Scenario 2, in order to stress the southeast interfaces.
- Scenario 4: Maximum dispatch from southwest. This examined operating conditions under stressed southwest interfaces.

Reliability criteria violations that occurred under normal (N-0) conditions are shown in Table 16 and Table 17. Table 16 shows substation voltage violations and Table 17 shows transmission line and transformer overloads. The dispatch condition under which a violation occurs is also shown in the tables.

Under system normal conditions substation voltage violations occur when voltages fall outside the 5% band around the nominal voltage rating. For example, under Scenario 1, the voltage at the Accra East substation is 0.94 p.u., which is lower than the low voltage limit of 0.95 p.u. Under Scenario 4, the voltage is even lower, at 0.92 p.u. The voltage at Accra East remains within the reliability limits and no violations are observed under Scenarios 2 and 3. This might be because the high dispatch from the Southeast generation enclave provides the required voltage support at Accra East.

As shown in Table 16, substations in the north, such as Bawku, Bolgatanga and Zebilla have a relatively high risk of voltage violations because violations occurred in all the 4 scenarios analyzed. Generation redispatch might therefore not be sufficient to resolve the low voltage problems. Reactive devices could be required to provide additional voltage compensation. Other bulk power substations had low voltage violations under 3 of the 4 dispatch scenarios, and might require further evaluation to determine if additional reactive compensation would be required. These include Achimota, Ayanfuri, Kpandu and Mallam.

**Table 16: Substation Voltage Violations Under Normal (N-0) Conditions**

| Substation Name | Nominal Voltage (kV) | Actual Voltage (kV) | Actual Voltage (p.u.) | Dispatch Scenario |
|---|---|---|---|---|
| Accra 4th BSP-161 | 161 | 150.8 | 0.94 | Scenario 1 |
| | 161 | 148.2 | 0.92 | Scenario 4 |
| Accra 4th BSP-330 | 330 | 312.7 | 0.95 | Scenario 4 |
| Accra East | 161 | 150.9 | 0.94 | Scenario 1 |
| | 161 | 148.5 | 0.92 | Scenario 4 |
| Accra Central | 161 | 148.7 | 0.92 | Scenario 1 |
| | 161 | 152.2 | 0.95 | Scenario 3 |
| | 161 | 146.1 | 0.91 | Scenario 4 |
| Achimota | 161 | 149.5 | 0.93 | Scenario 1 |
| | 161 | 152.6 | 0.95 | Scenario 3 |
| | 161 | 147.0 | 0.91 | Scenario 4 |
| Asawinso | 161 | 148.6 | 0.92 | Scenario 1 |
| | 161 | 150.8 | 0.94 | Scenario 3 |
| | 161 | 147.1 | 0.91 | Scenario 4 |
| Ayanfuri | 161 | 148.6 | 0.92 | Scenario 1 |
| | 161 | 150.9 | 0.94 | Scenario 3 |
| | 161 | 147.2 | 0.91 | Scenario 4 |
| Bawku | 161 | 150.9 | 0.94 | Scenario 1 |
| | 161 | 152.7 | 0.95 | Scenario 2 |
| | 161 | 152.0 | 0.94 | Scenario 3 |
| | 161 | 150.3 | 0.93 | Scenario 4 |
| Bolgatanga 161 kV | 161 | 151.1 | 0.94 | Scenario 1 |

| Substation Name | Nominal Voltage (kV) | Actual Voltage (kV) | Actual Voltage (p.u.) | Dispatch Scenario |
|---|---|---|---|---|
| | 161 | 152.9 | 0.95 | Scenario 2 |
| | 161 | 152.2 | 0.95 | Scenario 3 |
| | 161 | 150.6 | 0.94 | Scenario 4 |
| Bolgatanga 330 kV | 330 | 312.9 | 0.95 | Scenario 4 |
| Cape Coast | 161 | 150.9 | 0.94 | Scenario 4 |
| Ho | 69 | 64.4 | 0.93 | Scenario 1 |
| | 69 | 63.4 | 0.92 | Scenario 4 |
| Juabeso | 161 | 151.1 | 0.94 | Scenario 1 |
| | 161 | 149.9 | 0.93 | Scenario 4 |
| Kpandu | 69 | 63.1 | 0.91 | Scenario 1 |
| | 69 | 64.6 | 0.94 | Scenario 3 |
| | 69 | 61.9 | 0.90 | Scenario 4 |
| Kpeve | 69 | 63.4 | 0.92 | Scenario 1 |
| | 69 | 64.8 | 0.94 | Scenario 3 |
| | 69 | 62.4 | 0.9 | Scenario 4 |
| Mallam | 161 | 149.0 | 0.93 | Scenario 1 |
| | 161 | 152.7 | 0.95 | Scenario 3 |
| | 161 | 146.3 | 0.91 | Scenario 4 |
| Mim | 161 | 152.6 | 0.95 | Scenario 4 |
| Sogakope | 69 | 64.4 | 0.93 | Scenario 1 |
| | 69 | 65.5 | 0.95 | Scenario 3 |
| | 69 | 63.7 | 0.92 | Scenario 4 |
| Winneba | 161 | 149.0 | 0.93 | Scenario 1 |
| | 161 | 145.8 | 0.91 | Scenario 4 |
| Zebilla | 161 | 150.9 | 0.94 | Scenario 1 |
| | 161 | 152.7 | 0.95 | Scenario 2 |
| | 161 | 152.0 | 0.94 | Scenario 3 |
| | 161 | 150.3 | 0.93 | Scenario 4 |

Transmission line overloads occur under normal conditions when the power flow on the line exceeds the normal rating of the transmission line. For example, under dispatch Scenario 3, the power flow on the 161 kV Volta to Accra East Line Circuit 1 is 224.2 MW. This is 5.3% higher than the line's nominal rating of 213 kV. This is the only transmission line violation observed under normal conditions, and it would be resolved with GRIDCo's planned upgrade of the line. No violations were observed on transformers connecting bulk power stations. To a large extent, when all transmission facilities are in service, the transmission lines within the bulk power system are expected to operate within limits after the planned upgrades are complete.

Although no violations were observed on the transformers connecting bulk power stations, violations were observed on the 161/34.5 kV Asawinso transformer, which connect the bulk power station to the sub-transmission system. This was not assessed under the transmission planning study, but GRIDCo is expected to work with the Electricity Company of Ghana (ECG) to ensure power can be delivered reliably to customers.

**Table 17: Transmission Line and Transformer Thermal Violations Under Normal (N-0) Conditions**

| Transmission Line or Transformer | Nominal Rating (MW) | Actual Loading (MW) | Actual Loading (% of Rating) | Dispatch Scenario |
|---|---|---|---|---|
| 161 kV Volta to Accra East Line Cct 1 | 213 | | 105.3 | Scenario 3 |

Voltage and thermal violations that occurred under N-1 contingency conditions are shown in Table 18 and Table 19, respectively. The dispatch condition under which each violation occurred is also shown. Several contingencies could result in violations on the same monitored element. For each dispatch condition, only the most severe violation is shown for each monitored element. For example, as shown in Table 18, the voltage at the Anwomaso substation falls to 0.89 p.u. with the loss of the 330 kV Anwomaso Phase Shift transformer in dispatch Scenario 1. This is lower than the limit of 0.90 p.u. allowed under contingency conditions. Other contingencies could have resulted in low voltage violations at Anwomaso, but this violation is the only one shown for dispatch Scenario 1 because it is the most severe in that scenario. Similarly, as shown in Table 19, the 161 kV Volta to Accra East Line Circuit 1 line is overloaded at 138.4% of the nominal rating under dispatch Scenario 1 when the 161 kV Volta to Accra East Line Circuit 2 line is out of service. Other contingencies could also have resulted in an overload on the 161 kV Volta to Accra East Line Circuit 1 line under dispatch Scenario 1, but the overload at 138.4% is the only one shown in the table for that dispatch scenario because it is the most severe.

Substations with a high risk of voltage violations under contingency conditions include Asawinso, Ayanfuri, and Juabeso. Low voltage violations occur under all four dispatch conditions, therefore generation redispatch might not be able to resolve the low voltage problems. In addition, the voltages could be as low at 0.51 p.u. to 0.57 p.u., which could be very difficult from and could lead to voltage stability problems and voltage collapse. This might be mitigated with the addition of a 330/161 kV autotransformer at Dunkwa to connect the 330 kV and 161 kV systems at the Dunkwa substation.

**Table 18: Substation Voltage Violations Under Contingency (N-1) Conditions**

| Substation Name | Nominal Voltage (kV) | Actual Voltage (kV) | Actual Voltage (p.u.) | Contingency | Dispatch Scenario |
|---|---|---|---|---|---|
| Anwomaso | 161 | 143.9 | 0.89 | 330 kV Anwomaso Phase Shift Transformer | Scenario 1 |
| Anwomaso | 330 | 295.0 | 0.89 | 330 kV Anwomaso Phase Shift Transformer | Scenario 1 |
| Asawinso | 161 | 84.6 | 0.53 | 161 kV Asawinso to Juabeso Line | Scenario 1 |
| | 161 | 84.1 | 0.52 | 161 kV Juabeso to Mim Line | Scenario 2 |
| | 161 | 85.7 | 0.53 | 161 kV Asawinso to Juabeso Line | Scenario 3 |

| Substation Name | Nominal Voltage (kV) | Actual Voltage (kV) | Actual Voltage (p.u.) | Contingency | Dispatch Scenario |
|---|---|---|---|---|---|
| | 161 | 82.2 | 0.51 | 161 kV Asawinso to Juabeso Line | Scenario 4 |
| Ayanfuri | 161 | 91.3 | 0.57 | 161 kV Asawinso to Juabeso Line | Scenario 1 |
| | 161 | 90.9 | 0.56 | 161 kV Juabeso to Mim Line | Scenario 2 |
| | 161 | 92.3 | 0.57 | 161 kV Asawinso to Juabeso Line | Scenario 3 |
| | 161 | 88.9 | 0.55 | 161 kV Asawinso to Juabeso Line | Scenario 4 |
| Cape Coast | 161 | 137.0 | 0.85 | 161 kV Cape Coast to Aboadze Line | Scenario 2 |
| | 161 | 136.2 | 0.85 | 161 kV Cape Coast to Aboadze Line | Scenario 3 |
| Ho | 69 | 60.9 | 0.88 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 1 |
| | 69 | 59.7 | 0.87 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 4 |
| Juabeso | 161 | 137.8 | 0.86 | 161 kV Dunkwa to Ayanfuri Line | Scenario 1 |
| | 161 | 84.0 | 0.52 | 161 kV Juabeso to Mim Line | Scenario 2 |
| | 161 | 139.6 | 0.87 | 161 kV Dunkwa to Ayanfuri Line | Scenario 3 |
| | 161 | 136.6 | 0.85 | 161 kV Dunkwa to Ayanfuri Line | Scenario 4 |
| Kpandu | 69 | 61.7 | 0.89 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 2 |
| | 69 | 61.0 | 0.88 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 3 |
| | 69 | 57.7 | 0.84 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 4 |
| Kpeve | 69 | 59.7 | 0.86 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 1 |
| | 69 | 62.1 | 0.90 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 2 |
| | 69 | 61.4 | 0.89 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 3 |
| | 69 | 58.4 | 0.85 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 4 |
| Kumasi | 161 | 144.3 | 0.90 | 330 kV Anwomaso Phase Shift Transformer | Scenario 1 |
| Mim | 161 | 144.7 | 0.90 | 330 kV Anwomaso Phase Shift Transformer | Scenario 1 |
| | 161 | 144.0 | 0.89 | 161 kV Dunkwa to Ayanfuri Line | Scenario 4 |
| Sogakope | 69 | 61.5 | 0.89 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 1 |
| | 69 | 60.6 | 0.88 | 161 kV Akosombo to Asiekpe Line Circuit 2 | Scenario 4 |
| Wa | 161 | 140.3 | 0.87 | 161 kV Sawla to Wa Line | Scenario 1 |
| | 161 | 137.6 | 0.85 | 161 kV Sawla to Wa Line | Scenario 4 |
| Winneba | 161 | 140.5 | 0.87 | 161 kV Winneba to Aboadze T3 Line | Scenario 1 |

As shown in Table 19, several transmission lines and transformers could be overloaded under contingency conditions. They include the 161 kV Cape Coast to Aboadze T3 line, the 161 kV Dunkwa to New Obuasi line, the 161 kV Volta to Accra East double circuit line, 161 kV Winneba to Aboadze T3 line, and the 330/161 kV Aboadze transformers. The most severe are the 161 kV Volta to Accra East double circuit line and the 330/161 kV Aboadze transformers. Both are overloaded under multiple dispatch conditions, and might therefore be difficult to resolve with generation redispatch. The violation on the Volta to Accra East double circuit line would be resolved with GRIDCo's planned upgrade.

In addition to the violations shown, overloads were observed on the 161/34.5 kV Asawinso transformer, 161/34.5 kV New Tema transformer and the 161/34.5 kV Kpandu transformer, which connect the bulk power station to the sub-transmission system. These were not assessed under the transmission planning study, but GRIDCo is expected to work with the ECG to ensure power can be delivered reliably to customers.

**Table 19: Transmission Line and Transformer Thermal Violations Under Contingency (N-1) Conditions**

| Transmission Line/ Transformer | Nominal Rating (MW) | Actual Loading (MW) | Actual Loading (% of Rating) | Contingency | Dispatch Scenario |
|---|---|---|---|---|---|
| 161 kV Cape Coast to Aboadze T3 Line | 170 | 211.6 | 124.5 | 330 kV Accra 4BSP to Aboadze Line | Scenario 1 |
| | 170 | 241.0 | 141.8 | 330 kV Accra 4BSP to Aboadze Line | Scenario 4 |
| 161 kV Dunkwa to New Obuasi Line | 170 | 210.8 | 124.0 | 330 kV Dunkwa to Anwomaso Line | Scenario 1 |
| | 170 | 222.9 | 131.1 | 330 kV Dunkwa to Anwomaso Line | Scenario 4 |
| 161 kV Volta to Accra East Line Cct 1 | 213 | 294.7 | 138.4 | 161 kV Volta to Accra East Line Cct 2 | Scenario 1 |
| | 213 | 324.6 | 152.4 | 161 kV Volta to Accra East Line Cct 2 | Scenario 2 |
| | 213 | 354.5 | 166.4 | 161 kV Volta to Accra East Line Cct 2 | Scenario 3 |
| | 213 | 288.7 | 135.5 | 161 kV Volta to Accra East Line Cct 2 | Scenario 4 |
| 161 kV Winneba to Aboadze T3 Line | 170 | 220.3 | 129.6 | 330 kV Accra 4BSP to Aboadze Line | Scenario 4 |
| 330/161 kV Aboadze Transformer 1 | 200 | 279.0 | 139.5 | 330/161 kV Aboadze Transformer 2 | Scenario 1 |
| | 200 | 294.8 | 147.4 | 330/161 kV Aboadze Transformer 2 | Scenario 2 |
| | 200 | 333.8 | 166.9 | 330/161 kV Aboadze Transformer 2 | Scenario 4 |

In addition to the contingencies and violations discussed above, ICF's analysis identified other contingencies that could have even more severe consequences on GRIDCo's ability to continue to operate the bulk power system. These contingencies result in extremely low voltages from which the power system is unable to recover. Under actual operating conditions, the system operator might resort to load shedding to maintain system reliability, but the voltage instability could result in a system-wide blackout. The contingencies and some mitigating measures that were demonstrated as effective in resolving these violations are shown in Table 20.

The critical contingencies include the loss of the 330 kV Dunkwa to Anwomaso line, the loss of the 161 kV Sunyani to Mim Line, the loss of the 330/225 kV Bolgatanga Transformer, and the loss of the 161 kV Tamale to Buipe Line. The voltage instability caused by these contingencies occur under multiple dispatch conditions, therefore generation re-dispatch might be ineffective in resolving the violations. In addition to the contingencies shown in Table 20, ICF identified other critical contingencies that caused voltage collapse under a specific dispatch scenario. These could potentially be mitigated through re-dispatch.

**Table 20: Critical Contingencies and Mitigation Measures**

| # | Critical Contingency | Dispatch Scenarios | Impact | Potential Mitigation Measures |
|---|---|---|---|---|
| 1 | 330 kV Dunkwa to Anwomaso Line | 1, 2, 3, 4 | Voltage collapse | 2nd Circuit 330 kV Dunkwa – Anwomaso |
| 2 | 161 kV Sunyani to Mim Line | 1, 2, 3, 4 | Non convergence of power flow due to extremely low voltages in Mim, Juabeso and Asawinso area. | Add 30 MVAr capacitor bank at Mim, 20 MVAr at Juabeso and 25 MVAr at Asawinso |
| 3 | 161 kV Mim to Juabeso Line | 1, 3, 4 | Non convergence of power flow due to extremely low voltages in Mim, Juabeso and Asawinso area. | Solution for Sunyani – Mim mitigates this problem |
| 4 | 330 kV Aboadze to A4BSP Line | 1, 4 | Voltage collapse | 2nd Circuit 330 kV Aboadze – A4BSP. This may not be possible due to right of way issues. |
| 5 | 330/161 kV Bolgatanga Transformer | 1, 2, 3 | Non-convergence of power flow due to extremely Low voltages. | 2nd 330/161 kV Transformer at Bolgatanga |
| 6 | 330/225 kV Bolgatanga Transformer | 1, 2, 3, 4 | Voltage collapse | 2nd 330/225 kV Transformer at Bolgatanga |
| 7 | 161 kV Tamale to Buipe Line | 1, 2, 3, 4 | Non-convergence of power flow due to extremely Low voltages. | GRIDCo's planned 330 kV line from Anwomaso to Tamale resolves the problem. The line is expected to be in operation by 2020. |
| 8 | 161 kV Buipe to Kintampo Line | 1, 2, 3 | Non-convergence of power flow due to extremely Low voltages. | GRIDCo's planned 330 kV line from Anwomaso to Tamale resolves the problem. The line is expected to be operation by 2020. |

# IV. Conclusions and Recommendations

## Conclusions

ICF conducted a set of 3 studies to assess the reliability of the GRIDCo electric – Total Transfer Capability (TTC) analysis, Import/Export Capability studies, and Transmission Security Analysis (TSA). TTC analysis determines the amount of power that can be delivered to or from an area without violating reliability limits. TTC is a measure of the adequacy of the transmission system. If the demand in an area exceeds the TTC for that area, demand might be curtailed to maintain reliability. The Import/Export Capability studies determined the transfer capabilities for generation and load centers. ICF calculated the simultaneous export limits for the generation centers and the simultaneous import limits for major load centers. TSA assesses the ability of the power system to continue operating following the loss of major elements such as transmission lines and transformers. ICF examined the operation of the Ghana bulk power system during a representative peak period, and determined if reliability criteria violations would occur under contingency conditions for various dispatch scenarios.

ICF found that inadequate firm transfer capabilities in particular could limit the ability to meet demand in some regions if some major transmission lines or transformers are out of service. GRIDCo's planned transmission system upgrades and additions would improve the outlook for TTCs, but additional improvements might be required for interfaces such as the Southeast zone to the Ashanti zone. ICF also found that the 161 kV Volta to Accra East line severely limits the export capability from the Tema generation pocket. Because of the number and total capacity of generators in the Tema zone it is important to ensure that there is sufficient transfer capability to deliver the power to load centers. Inadequate export capability can affect the reliability of the GRIDCo system.

The TSA study identified potential severe voltage violations on substations such as Asawinso, Ayanfuri and Juabeso and Kpandu. Under contingency conditions some of the voltages could extremely low, and even result in a risk of voltage collapse and blackout. Low voltages could occur at several other substations under both normal and contingency conditions. Some of the voltage violations could be resolved by generation redispatch, but because of the prevalence GRIDCo can perform additional analysis and determine if other mitigation measures would be required. The study also identified transmission lines and transformers such as the 161 kV Volta to Accra East line and the 330/161 kV Aboadze transformer that are overloaded under contingency conditions. GRIDCo's planned upgrades might resolve these violations, but GRIDCo should perform studies to determine if any of these violations would persist after the upgrades, and whether any additional upgrades would be required.

In addition to these contingencies and violations ICF's analysis identified other contingencies that could have even more severe consequences on GRIDCo's ability to continue to operate the bulk power system. These contingencies result in extremely low voltages from which the power system is unable to recover. Under actual operating conditions, GRIDCo might resort to load shedding to maintain system reliability, but the voltage instability could result in a system-wide blackout. ICF identified some mitigating measures that were demonstrated as effective in resolving these violations. GRIDCo should validate the results of the study and determine if the identified measures of other solutions would be the most effective methods to resolve the violations.

## RECOMMENDATIONS

GRIDCo's transmission planning studies can validate the voltage violations, transmission line overloads, and critical contingencies identified in ICF's TSA study and assess potential solutions that can resolve the violations. ICF recommends that GRIDCo expedite the review of the 2011 Transmission System Master Plan and its subsequent implementation. The model assumptions behind the study for the 2011 Transmission Master Plan have changed. There is therefore the need to develop new modeling assumptions, re-assess the current configurations of the grid and examine options to improve the grid so it would operate reliably even under contingency conditions.

GRIDCo should also expedite the development and implementation of its proposed projects because many have a significant impact on reliability. This includes projects that are critical in serving major load centers such as Accra. Some of these projects are the A4BSP, the Volta to Achimota line and the Volta to Accra East line. Further, as discussed, projects such as the Volta to Accra East transmission line upgrade would significantly improve the ability to evacuate generation from the southeast generation center and deliver to major load centers. Without some of these projects there is a risk that generation will be bottled, or that demand would be curtailed under emergency conditions. Because of the increase in generation capacity around Tema it is important to ensure there is sufficient transmission capacity that will enable the use of the new generation to meet resource adequacy needs.

The planned transmission upgrades and additions assumed to be in service by 2020 in ICF's study are shown in Table 2 and Table 3. If these projects are delayed, transfer capabilities could fall below the levels calculated in this study, which could adversely affect system reliability and performance, especially during contingency conditions.

ICF also recommends that GRIDCo incorporate transfer capability studies into its transmission planning process. This will help assess the adequacy of the transmission system for inter zonal transfers, which will ensure there is sufficient capacity to deliver the generation capacity from supply resource locations to load centers. The transfer capabilities would be required for the least regrets modeling for future updates of the Integrated Power System Master Plan (IPSMP). Assessment of simultaneous import capability for load centers such as Accra and Kumasi that do not have internal generation will help ensure that GRIDCo can serve the Bulk Power Stations reliably, and will not have to resort to load curtailment to maintain reliability even under contingency conditions. Assessment of simultaneous export capability for generation centers such as Aboadze, Akosombo and Tema, will determine if the generation capacity can be reliably evacuated, and what upgrades would be required to minimize the risk of trapped generation.

ICF's study focused on the bulk power system and did not include a detailed assessment of the step-down transformers that connect the bulk power system to the sub-transmission system, although ICF observed violations on the 161/34.5 kV Asawinso transformer, the 161/34.5 kV New Tema transformer and the 161/34.5 kV Kpandu transformer. GRIDCo should work with

ECG to perform a more detailed analysis to determine if violations would occur on any other transformers and develop appropriate solutions.

Any mitigation measures or solutions examined in ICF's study are only preliminary or high level in nature. GRIDCo would need to do detailed analysis to validate the solutions, analyze alternatives and select the projects that best meet system needs cost effectively. GRIDCo would also have to perform more detailed engineering studies to determine the actual design, routing, interconnection substations, and other details required to implement the project.

Update the database on status of renewable and other generation development in Ghana. GRIDCo should consider developing a generation interconnection queue that will provide non-confidential information on the status of proposed renewable and other generation projects in the country. The generation interconnection queue might include information such as capacity and type of plant, proposed interconnection location, expected in service date, and status. This will be a useful tool for regulators, planners, developers, investors, and other stakeholders interested in the Ghana electric sector. GRIDCo should also continuously monitor and include renewable energy and other local (embedded) generation in the planning process because these could affect planning (e.g. load forecast, congestion, power flow patterns, system protection and stability) and system operation (e.g. commitment and dispatch).

Additional recommendations can be found in the report on ICF's solar penetration study conducted as part of the IRRP study. The study is described in ICF's report, Ghana Solar Photovoltaic Penetration Study, dated November 2018.

# G. SOLAR PV PENETRATION ANALYSIS

In 2017 and 2018, the IRRP project analysed the potential grid impacts of integrating solar PV in the northern region of the country. This analysis was helpful in determining the potential scale of PV that could be integrated into the existing Ghana transmission grid, and the impacts thereof.

The report below summarizes the work done for the solar PV penetration analysis.

# Ghana Solar Photovoltaic Penetration Study

Final Report

Submitted by ICF
November 2018

# Ghana Integrated Resource and Resilience Planning Program

## Ghana Solar PV Penetration Study

This publication was produced for the United States Agency for International Development, Ghana Mission, by ICF through Cooperative Agreement AID-641-LA-16-0001.

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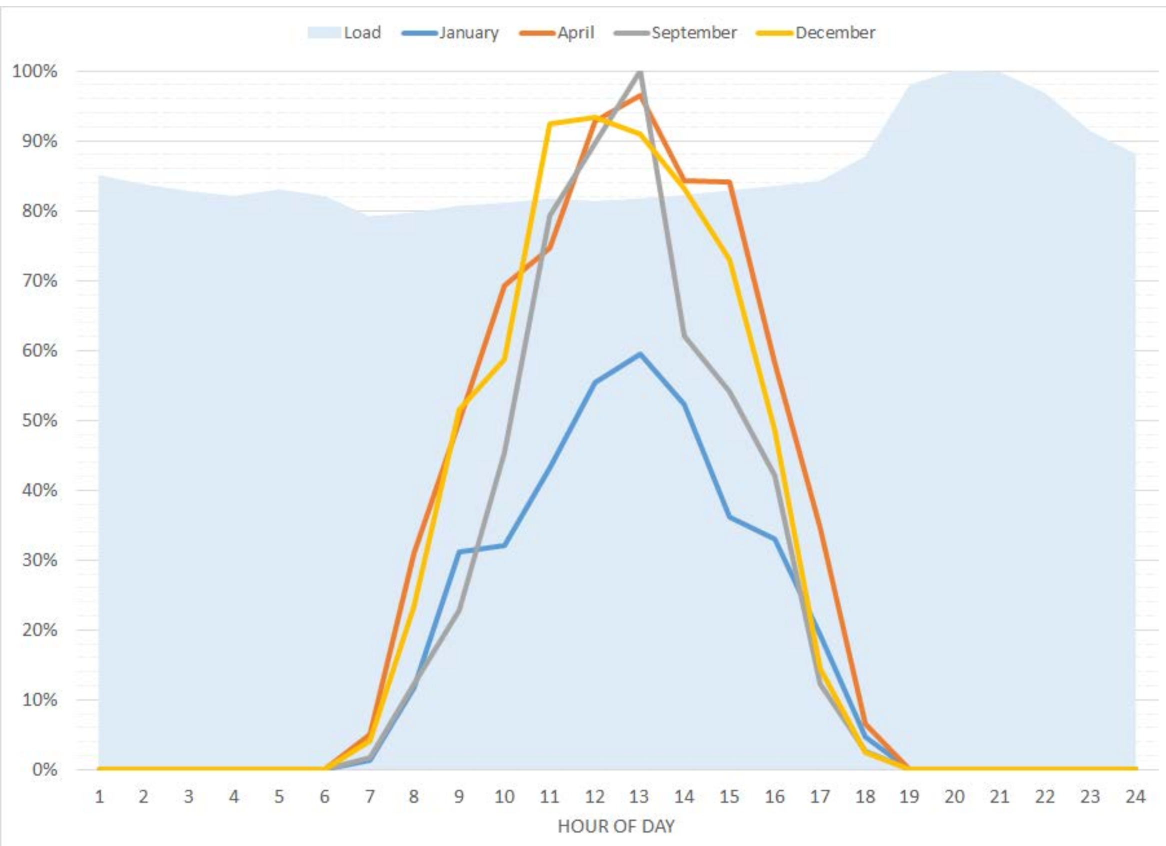
# EXECUTIVE SUMMARY

ICF conducted a study under the USAID-funded Integrated Resource and Resilience Planning (IRRP) project to evaluate the potential for solar photovoltaic (PV) penetration in Ghana. This study is a high-level assessment designed to provide an indication of the solar PV penetration limits, and the levels at which mitigation might be required. ICF examined only a single snapshot of system operation and a few selected contingencies.

The study focused on interconnection locations in northern Ghana because of the large solar PV resource potential in that part of the country. ICF conducted the analysis for a representative off-peak demand period in 2020. ICF selected the off-peak period because the peak period of solar output coincides with the off-peak demand period, as shown in Figure ES-1. In Figure ES-1, system load and historical average monthly solar PV output have been normalized to illustrate the lack of correlation between peak solar output and system peak demand. System load is normalized relative to the peak load, while average monthly solar PV output peaks at approximately 13 MW.

**Figure ES-1: Normalized Ghana System Load and Normalized Average Monthly Solar PV Output**




The study examined a Base Case without the solar PV plants and four solar PV penetration scenarios that assessed the impact of various levels of solar integration, up to a penetration level of 30% of off-peak demand. The scenarios examined were:

- **Base Case:** This is a business-as-usual scenario representative of the off-peak period during the 2020 operating year, and assuming no solar PV is added to the grid in northern Ghana.

- **Scenario 1:** This is similar to the Base Case, but solar PV plants that currently have proposed to interconnect in northern Ghana and have requested studies or are currently under study by GRIDCo are assumed to be in operation.
- **Scenario 2:** This is similar to Scenario 1, but additional solar PV plants are added to achieve a penetration level of approximately 10% of off-peak demand.
- **Scenario 3:** This is similar to Scenario 1, but additional solar PV plants are added to achieve a penetration level of approximately 20% of off-peak demand.
- **Scenario 4:** This is similar to Scenario 1, but additional solar PV plants are added to achieve a penetration level of approximately 30% of off-peak demand.

In conformance with the Ghana Renewable Energy (RE) Grid Code, ICF modeled the solar PV plants at 0.95 lagging and 0.925 leading power factor. This means the inverters can produce reactive power to boost substation voltages when voltages are low, and they can also absorb reactive power and reduce substation voltages when voltages are high. The solar PV plants can therefore provide voltage support and improve system reliability.[1] Table ES-1 summarizes the key assumptions for each solar penetration scenario.

ICF analyzed the performance of the GRIDCo bulk power system under selected contingencies that can affect system operation and system stability, including:

- Loss of major transmission lines and transformers;
- A three-phase fault on a major transmission line;
- The loss of a major generating unit that provides essential reliability services;

The results of the study, summarized in Figure ES-2, show that even at penetration levels of 30% of off-peak demand, or 790 MW of solar PV, the grid is not at risk of reliability criteria violations under steady state conditions. In fact, its response to contingencies that affect system voltages improves as solar PV penetration increases because the solar PV plants are equipped with inverters that provide voltage support through reactive power controls. Without this capability high voltage violations would occur under steady state conditions. To maintain grid reliability new solar PV plants should have reactive power control capability in line with the Ghana RE Grid Code.

Table ES-2 shows that penetration levels are limited by the transient stability of the grid. Under the contingency conditions that were tested, the grid is able to return to a stable state for penetration levels up to approximately 10% of the off-peak demand. Between 10% and 20% there is a risk that the system might not return to a stable state after the occurrence of contingencies such as the loss of a major generator the provides essential reliability services, a three-phase fault of a major transmission line, and the unplanned loss of a major transmission line. The implementation of mitigation measures to increase penetration levels was not included in the scope of the study, but should be examined as a future scope of work. These measures might include the installation of power system stabilizers, addition of fast-response and flexible generation, deployment of storage devices, and the use of demand response. Given its location and fast-ramping capability, the use of the Bui Hydro Plant should also be considered as an option to improve solar PV integration.

[1] It would be useful to assess whether other measures would also be cost-effective in improving the integration of renewable resources.

### Table ES-1: Solar PV Plant Additions

| Generator Name | Capacity (MW) | | | |
|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| Planned Solar PV 1 | 50 | 50 | 50 | 50 |
| Planned Solar PV 2 | 20 | 20 | 20 | 20 |
| Planned Solar PV 3 | 20 | 20 | 20 | 20 |
| Planned Solar PV 4 | 20 | 20 | 20 | 20 |
| Planned Solar PV 5 | 25 | 25 | 25 | 25 |
| Planned Solar PV 6 | 20 | 20 | 20 | 20 |
| Planned Solar PV 7 | 50 | 50 | 50 | 50 |
| Planned Solar PV 8 | 30 | 30 | 30 | 30 |
| Unplanned Solar PV 1 | | 25 | 25 | 25 |
| Unplanned Solar PV 2 | | 50 | 50 | 50 |
| Unplanned Solar PV 3 | | | 50 | 50 |
| Unplanned Solar PV 4 | | | 50 | 50 |
| Unplanned Solar PV 5 | | | 50 | 50 |
| Unplanned Solar PV 6 | | | 30 | 30 |
| Unplanned Solar PV 7 | | | | 25 |
| Unplanned Solar PV 8 | | | | 25 |
| Unplanned Solar PV 9 | | | | 150 |
| Unplanned Solar PV 10 | | | | 70 |
| Unplanned Solar PV 11 | | | | 30 |
| Total Solar PV Generation (MW) | 235 | 310 | 490 | 790 |
| Total Load (MW) | 2,573 | 2,573 | 2,573 | 2,573 |
| Penetration Level (%) | 9% | 12% | 19% | 31% |

### Table ES-2: Summary of Results

| System Condition/ Contingency | Base Case (N/A) | Scenario 1 (9%) | Scenario 2 (~ 10%) | Scenario 3 (~ 20%) | Scenario 4 (~ 30%) |
|---|---|---|---|---|---|
| **Steady State Voltage Violations** | | | | | |
| **Steady State Line or Transformer Overloads** | | | | | |
| **Transient Stability – Loss of Major Generator** | | | | | |
| **Transient Stability – Three-Phase Fault** | | | | | |
| **Transient Stability – Loss of Major Transmission Line** | | | | | |

The results show that rapid integration of large scale renewable generation without appropriate mitigation can lead to system stability problems. A potential strategy for renewable integration is to add renewable resources gradually and implement the appropriate mitigation measures as the need arises.

As mentioned, this study is a high-level assessment designed to provide an indication of the solar PV penetration limits, and the levels at which mitigation might be required. A more comprehensive assessment is required to determine a more refined measure of the penetration limit and develop a strategy for renewable integration. Next steps might include:

1. Perform a more detailed assessment including examining additional periods of operation and additional contingencies. This could be achieved by carrying out the following:
    a. Determine the locations of new solar PV plants in consultation with GRIDCo.
    b. Work with GRIDCo to determine additional contingencies that should be examined.
    c. Perform production cost (hourly or sub-hourly security constrained unit commitment and economic dispatch) or other appropriate simulation of the operation of the bulk power system and select additional periods of operation for further analysis. These could be stressed periods such as periods with low system inertia, low ramping capacity online, low net load, or significant congestion.
    d. Perform the steady state and transient stability analysis for the selected hours.
2. Perform additional studies to assess other aspects of the impact of renewable penetration, such as how the change in net demand can change over a predefined short interval, and its impact on ramping needs.
3. Perform additional studies to examine the effects of solar PV penetration in all parts of Ghana, as per the least-regrets and BAU scenarios of the IPSMP.
4. Determine mitigation measures to increase penetration limits.
5. Determine the ability to utilize the Bui Plant strategically to improve renewable integration.
6. Update the database on status of solar plant development through the implementation of a GRIDCo generation interconnection queue.
7. Extend the study to cover other aspects of system planning that can support the integration of renewables, including:
    a. The feasibility of using solar PV as a non-wires alternative to transmission projects;
    b. Value of solar studies that can quantifying other benefits of deploying solar PV resources.

# I. INTRODUCTION

Once commissioned, the Bui Hydropower Plant has provided an alternative electricity supply outside Ghana's traditional generation centers in the southeast and southwest of the country. The plant is located at the south end of the Bui National park, in the north-western part of the country, and it is the only major generation station outside the southeast and southwest generation centers. Prior to the development of the Bui Hydro plant, Ghana relied exclusively on power from generation stations in Akosombo, Akuse, and Tema in the Southeast, and from Aboadze in the Southwest. When operating, the Bui Plant (located in the north-western part of Ghana) can reduce the need to import power over long distances to load centers in Kumasi and the northern part of the country. In addition to its strategic location, the plant could provide balancing services to support the integration of solar photovoltaic (PV) generation resources. This is an important advantage given the large solar PV potential in the northern part of the country.

This ICF study conducted under the USAID-funded Integrated Resource and Resilience Planning (IRRP) project evaluated the potential for solar PV penetration in northern Ghana. It is a high-level assessment designed to provide an indication of the solar PV penetration limits, and the levels at which mitigation might be required. ICF examined a single snapshot of system operation and a few selected contingencies. The study assesses the implications on the grid for penetration levels up to 30% of Ghana's off-peak demand. The analysis was conducted for the 2020 study period. As discussed in more detail later in the report, ICF's analysis focused on the off-peak demand period because the period of peak solar output coincides with the off-peak period. The study included solar PV generation plants that have proposed to interconnect in northern Ghana and are currently under study by GRIDCo. ICF modeled these solar PV plants as firmly planned units and added incremental unplanned capacity where necessary to achieve the target penetration level in each of the scenarios examined.

This report discusses the assumptions, methodology, and results of the study. It identifies constraints and other limitations on the bulk power system that could affect the ability to integrate solar PV generation. It also describes system improvements that could resolve the identified limitations and enhance the penetration of solar PV in the north.

The rest of the report is divided into the following sections:

II. Assumptions
III. Study Methodology
IV. Modeling Results – Steady State Analysis
V. Modeling Results – Transient Stability Analysis
VI. Key Findings and Next Steps

# II. ASSUMPTIONS

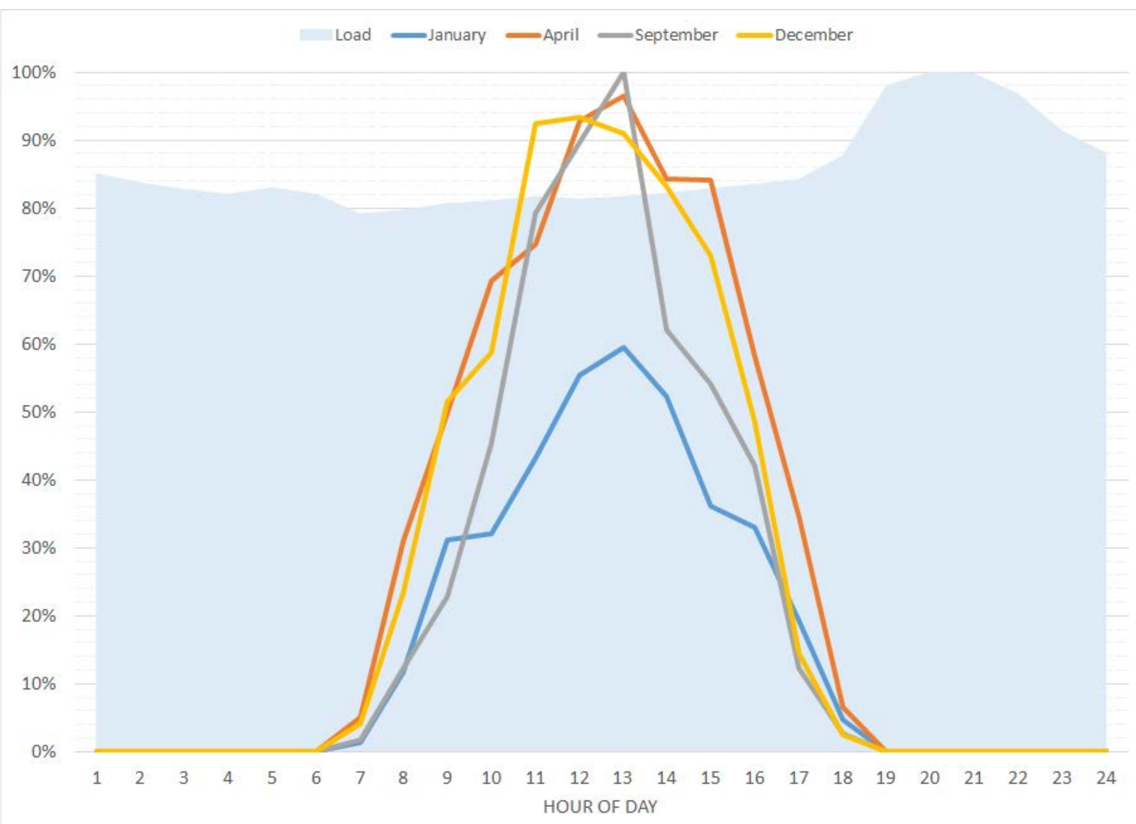
This section discusses the key assumptions used in the study.

## II.1. MODEL DEVELOPMENT

Model simulations were developed for the 2020 operating year. Figure 1 shows a normalized 24-hour load profile of the Ghana bulk power system, overlaid with the normalized profile of a representative solar PV plant in Ghana during different months of the year. In Figure 1, system load and historical average monthly solar PV output have been normalized to illustrate the lack of correlation between peak solar output and system peak demand. System load is normalized relative to the peak load, while average monthly solar PV output peaks at approximately 13 MW.

The solar output is not correlated to the demand. The peak demand starts between 6 p.m. and 7 p.m. when the solar output is almost down to zero. The model simulations were performed for snapshots of system conditions representative of off-peak loading conditions because the period of peak solar output coincides with the off-peak demand period. An analysis of the Ghana load profile showed that the average off-peak load is 80% of the peak load. In developing the off-peak loading conditions, ICF assumed that loads such as the Volta Aluminum Company (VALCO) smelter and the mines are non-conforming loads, and therefore these did not change between peak and off-peak periods. Based on this analysis ICF modeled an off-peak demand of approximately 2,573 MW.

**Figure 1: Normalized Ghana System Load and Normalized Average Monthly Solar PV Output**



For this analysis, ICF assumed the Bui Power Plant to be a peaking plant, consistent with its expected operation on the bulk power system.[2] ICF therefore assumed it to be unavailable during the peak dispatch of the solar PV plants. The off-peak period therefore represents stressed grid conditions for solar PV generation. The Bui Plant would be offline because it is currently operating as a peaking plant. In addition, solar output would be high at a time when system demand would be relatively low, leading to low net demand and the likelihood that some other flexible generators will be offline.

However, because of its strategic location and fast-ramping capability, future studies or additional sensitivities can examine conditions under which the Bui Plant can provide balancing services to improve renewable resource integration.

## II.2. Scenarios Examined

The study examined a Base Case without the solar PV plants and four solar PV penetration scenarios that assessed the impact of various levels of solar integration, up to a penetration level of 30% of load. The scenarios examined were:

- **Base Case:** This is a business-as-usual scenario representative of the off-peak period during the 2020 operating year, and assuming no solar PV is added to the grid in northern Ghana.
- **Scenario 1:** This is similar to the Base Case, but solar PV plants that currently have proposed to interconnect in northern Ghana and have requested studies or are currently under study by GRIDCo are assumed to be in operation.
- **Scenario 2:** This is similar to Scenario 1, but additional solar PV plants are added to achieve a penetration level of approximately 10% of off-peak demand.
- **Scenario 3:** This is similar to Scenario 1, but additional solar PV plants are added to achieve a penetration level of approximately 20% of off-peak demand.
- **Scenario 4:** This is similar to Scenario 1, but additional solar PV plants are added to achieve a penetration level of approximately 30% of off-peak demand.

## II.3. Existing Generation

Table 1 shows the power plants that ICF assumed to be in service by 2020, based on information from GRIDCo.[3] These were modeled in the Base Case and the penetration scenarios. Some of these plants shown in the table below were not included as firm builds in the Ghana IPSMP work that the IRRP project is working on. These power plants (e.g., GPGC, Ayitepa, and VRA wind plants) were included in the GRIDCo Base Case PSS/E model, and therefore ICF assumed these plants to be part of the Base Case for this study.

Dispatch in each scenario depended on network conditions and the incremental solar PV added to the case.

[2] 2017 Electricity Supply Plan for the Ghana Power System, p. 36.
[3] These power plants are very similar to (but not exactly the same as) the ones assumed in the Ghana IPSMP report. For example, the Ghana IPSMP report did not specify any individual potential wind or solar plant.

**Table 1: Existing Generation Plants in the Ghana Bulk Power System**

| Generator Name | Type | Installed Capacity (MW) |
|---|---|---|
| Akosombo Hydroelectric Power Plant | Hydro | 1,020 |
| AMERI Power Plant | Gas | 250 |
| Kpong Hydroelectric Power Plant | Hydro | 160 |
| Takoradi Thermal Power Plant (TAPCo) | LCO/Gas | 330 |
| Takoradi Thermal Power Plant (TICo) | LCO/Gas | 340 |
| Sunon Asogli Power Plant | Gas | 200 |
| Sunon Asogli II Power Plant | Gas | 360 |
| AKSA | HFO/Gas | 260 |
| KarPower II | HFO/Gas | 470 |
| GPGC | HFO/Gas | 112 |
| Amandi | Gas | 203 |
| Early Power* | LPG/Gas | 400 |
| CEN Power | LCO/Gas | 360 |
| Tema Thermal Power Plant (TT1PP) | LCO/Gas | 126 |
| Tema Thermal Power Plant (TT2PP) | Gas | 80 |
| CENIT | LCO | 126 |
| Kpone Thermal Power Plant (KTPP) | Diesel/Gas | 220 |
| MRP | Gas | 80 |
| Bui Hydro Electric Power Plant | Hydro | 400 |
| Upwind Ayitepa Wind Generator | Wind | 225 |
| VRA Wind Generator Site 1 | Wind | 75 |
| VRA Wind Generator Site 2 | Wind | 75 |

## II.4. NEW SOLAR PV PLANTS

The solar PV plants added in each scenario are shown in Table 2. As mentioned, no new solar PV plants were added to the Base Case. In Scenario 1, an anticipated 235 MW of solar PV was assumed to interconnect to the GRIDCo system in the northern region. This represents all of the solar PV plants that have requested studies or are currently under study by GRIDCo. For the purposes of this study, ICF assumed these projects are likely to be placed into service, and therefore they are referred to as “planned” solar PV plants in this study. The PSS/E studies assumed that the full maximum solar output would be fed into the grid at the time when the solar output is the highest (typically between 12 PM and 1 PM, as shown in Figure 1).

In Scenario 2, additional unplanned solar PV generation was added to achieve a penetration level of approximately 10% of off-peak demand of approximately 2,573 MW. This resulted in a total solar PV generation of 310 MW in Scenario 2. In Scenario 3 and Scenario 4, unplanned solar PV generation was added to achieve penetration levels of approximately 20% and 30%, respectively. The total generation added was 490 MW in Scenario 3 and 790 MW in Scenario 4. The additional solar PV plants included in Scenarios 2 through 4 are referred to as “unplanned” solar PV plants in this study.

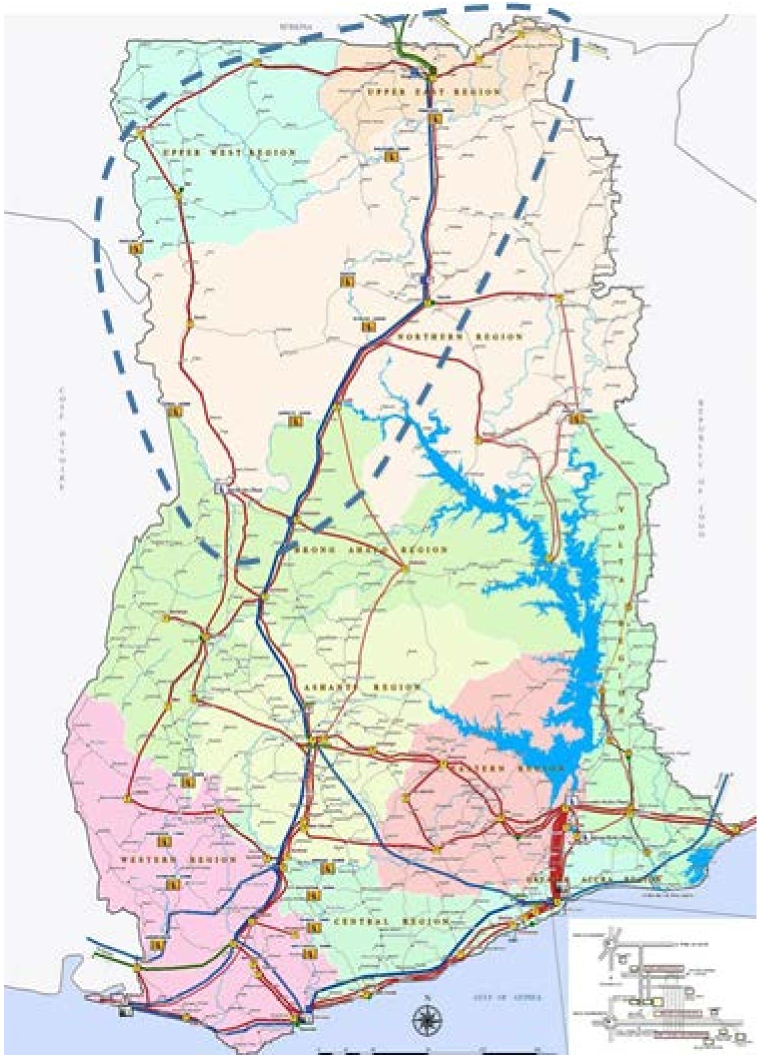
The solar PV plants were modeled at 0.95 lagging and 0.925 leading power factor in conformance with the Ghana Renewable Energy (RE) Grid Code. This means the inverters can produce reactive power to boost substation voltages when voltages are low, and they can also absorb reactive power and reduce substation voltages when voltages are high. The solar PV plants can therefore provide voltage support and improve system reliability.

**Table 2: Solar PV Plant Additions**

| Generator Name | Capacity (MW) | | | |
|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| Planned Solar PV 1 | 50 | 50 | 50 | 50 |
| Planned Solar PV 2 | 20 | 20 | 20 | 20 |
| Planned Solar PV 3 | 20 | 20 | 20 | 20 |
| Planned Solar PV 4 | 20 | 20 | 20 | 20 |
| Planned Solar PV 5 | 25 | 25 | 25 | 25 |
| Planned Solar PV 6 | 20 | 20 | 20 | 20 |
| Planned Solar PV 7 | 50 | 50 | 50 | 50 |
| Planned Solar PV 8 | 30 | 30 | 30 | 30 |
| Unplanned Solar PV 1 | | 25 | 25 | 25 |
| Unplanned Solar PV 2 | | 50 | 50 | 50 |
| Unplanned Solar PV 3 | | | 50 | 50 |
| Unplanned Solar PV 4 | | | 50 | 50 |
| Unplanned Solar PV 5 | | | 50 | 50 |
| Unplanned Solar PV 6 | | | 30 | 30 |
| Unplanned Solar PV 7 | | | | 25 |
| Unplanned Solar PV 8 | | | | 25 |
| Unplanned Solar PV 9 | | | | 150 |
| Unplanned Solar PV 10 | | | | 70 |
| Unplanned Solar PV 11 | | | | 30 |
| Total Solar PV Generation (MW) | 235 | 310 | 490 | 790 |
| Total Load (MW) | 2,573 | 2,573 | 2,573 | 2,573 |
| Penetration Level (%) | 9% | 12% | 19% | 31% |

The portion of the grid in northern Ghana where the solar plants were sited is shown in Figure 2, see dashed blue line. It covers an area ranging from Bui and Kintampo in the south to Tumu, Bolgatanga, and Bawku in the north.

**Figure 2: Area of Ghana Grid Selected (dashed line) for Solar PV Interconnection**

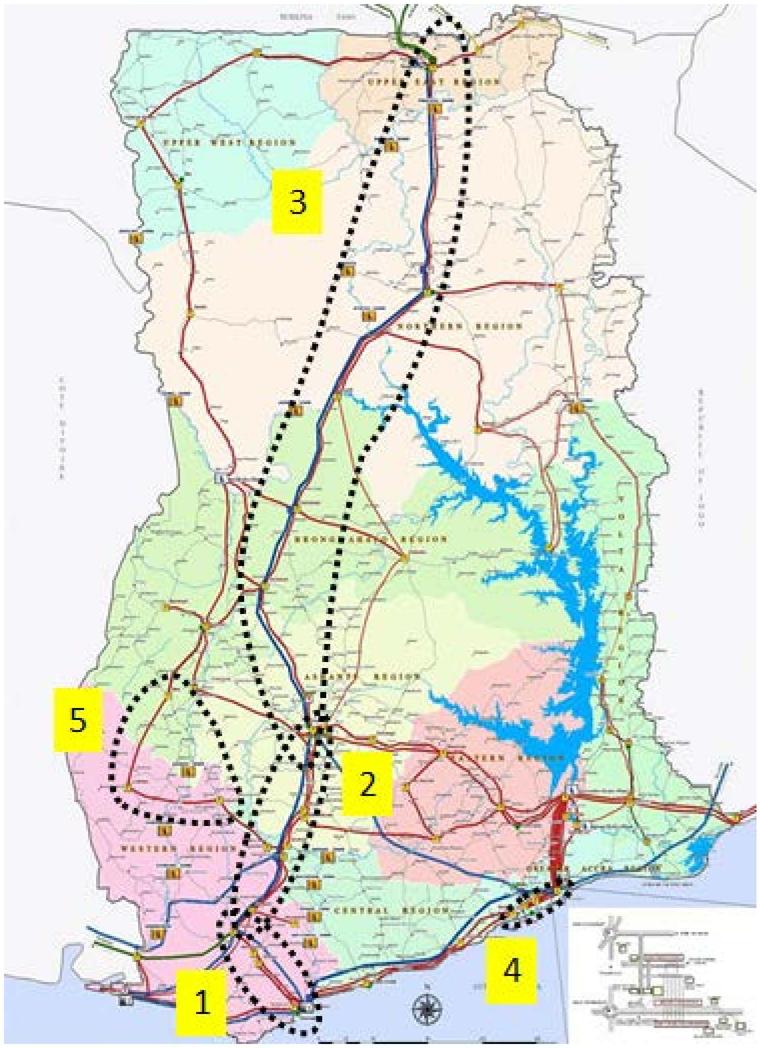



## II.5. TRANSMISSION ADDITIONS

Planned transmission lines additions and upgrades that are expected to be completed by 2020 were assumed to be in service in the study. As shown in Figure 3, they include:

1. The new 1,000 megavolt-ampere (MVA), 330 kilovolt (kV) Aboadze-Prestea transmission line
2. The new 1,000 MVA, 330 kV Prestea-Kumasi transmission line
3. The new 1,000 MVA, 330 kV Kumasi-Kintampo-Tamale-Bolgatanga line and interconnecting substations
4. The upgrade of 161 kV Volta-Achimota transmission line from two 213 MVA single circuit lines to a 488 MVA double circuit line
5. The new 161 kV substation at Juabeso, and completion of the 364 MVA, 161 kV Asawinso-Juabeso-Mim line

**Figure 3: Selected Transmission Additions and Upgrades**




## II.6. SELECTED RELIABILITY CRITERIA

GRIDCo’s planning criteria for transmission lines requires that lines operate within their thermal ratings under normal operating conditions. These criteria are specified in Ghana’s National Electricity Grid Code, which was established by the Energy Commission. Under contingency conditions, they can be operated up to 110% of the normal rating for a relatively short period to enable operators to adjust the system and prepare for the next emergency.

Transformers in the GRIDCo system also operate up to 100% of their nominal rating under normal conditions, and up to 120% of the rating under contingency conditions.

Substations are also expected to operate with specific limits to maintain system reliability. Within the GRIDCo network, substations are expected to operate within a 5% band of the nominal voltage level under normal conditions, and within a 10% band under contingency conditions. Therefore, under normal conditions voltages should remain within 95% and 105% of the nominal rating, also expressed as 0.95 per unit (p.u.) and 1.05 p.u. For a 161 kV system, the range would be 153 kV and 169 kV. Excessively low voltages can result in system collapse and blackout.

For this study, ICF used reliability criteria consistent with GRIDCo's planning criteria. This is summarized in Table 3.

**Table 3: Transmission Line and Substation Planning Criteria**

| Asset/Equipment | Condition | Low Limit | High Limit |
|---|---|---|---|
| Transmission Lines | Normal | N/A | 100% of Nominal Rating |
| Transmission Lines | Contingency | N/A | 110% of Nominal Rating |
| Transformers | Normal | N/A | 100% of Nominal Rating |
| Transformers | Contingency | N/A | 120% of Nominal Rating |
| Substation (Voltage) | Normal | 0.95 p.u. | 1.05 p.u. |
| Substation (Voltage) | Contingency | 0.90 p.u. | 1.10 p.u. |

In line with the National Electricity Grid Code, GRIDCo is also required to ensure that the bulk power system operates within specified frequency limits. Under normal conditions, system frequency should remain within a 200-megahertz (MHz) band around the nominal system frequency of 50 hertz (Hz). This means the frequency should remain between 49.8 Hz and 50.2 Hz at all times during normal system operation.

Under contingency conditions the allowed deviation increases to 500 MHz, but the frequency is expected to return to the 200 MHz band within 10 minutes. This means the frequency can be as low as 49.5 Hz or as high as 50.5 Hz under contingency conditions, but it should return to the accepted 49.8 Hz to 50.2 Hz range within 10 minutes.

# III. STUDY METHODOLOGY

ICF performed both steady state transmission security analysis and transient stability analysis to assess the performance of the Ghana bulk power system under various solar penetration scenarios in order to test if the grid would continue to operate reliably, as per the specific grid planning and operational criteria. These studies also assess the ability of the power system to continue operating following the loss of major elements such as transmission lines, transformers, and even generators—i.e., under contingency conditions.

## III.1. STEADY STATE ANALYSIS

ICF examined the steady state operation of the power system under normal (N-0) and contingency (N-1) conditions. Normal conditions assume all transmission facilities are in operation, while contingency conditions assume the loss of one major transmission line or transformer. The system was monitored for reliability violations such as line overloads and extreme (high or low) substation voltage violations. Normal conditions assume all network elements are in operation. By comparing the results of the solar PV penetration scenarios to that of the Base Case without the solar PV plants, ICF determined if the solar PV penetration would result in incremental reliability criteria violations that would affect the operation of the grid.

Because the solar PV plants were concentrated in the north of the country, the contingency analysis focused on major 161 kV and 330 kV transmission lines in the north.

## III.2. TRANSIENT STABILITY ANALYSIS

ICF performed the transient stability analysis to determine the ability of the power system to return to a stable state following sudden changes such as transmission system faults and loss of major generators. In the Ghana bulk power system, solar PV generation displaces fast-acting conventional generation, such as combined cycle and combustion turbine units that provide primary frequency response and other essential reliability services that support the transient stability of the grid. Transient stability analysis can determine the threshold at which severe reliability problems start to occur. This can establish the solar PV resource penetration limit for the Ghana bulk power system. Increasing solar PV penetration beyond the limit would require mitigation measures.

ICF examined selected contingencies that can affect system stability, including:

- a three-phase fault on a major transmission line,
- an unplanned outage of a transmission line,
- the loss of a major generating unit that provides essential reliability services, and
- the potential loss of the interconnected solar generation plants.

The three-phase fault was designed to test the ability of the system to return to a stable operating point following the momentary loss of the 161 kV Sawla to Wa line, while the line outage contingency assessed the impact of the unplanned outage of the 330 kV Tamale to Kintampo line.

The generator outage contingency tested system stability after the loss of a generating unit at Akosombo, a major unit that provides flexibility to the system and enables that system to respond quickly to contingences. The Akosombo hydroelectric generation units are large, flexible units that can quickly ramp up or down in response to changes in the system. They provide inertia, primary frequency response, and other essential reliability services that enhance the stability of the grid. The sudden loss of a unit at Akosombo would reduce the available generation that can adjust and maintain system stability. Ensuring system stability with increasing penetration of solar PV, especially in the event of the loss of one of the hydro units can become difficult. The analysis helps determine the limit at which severe reliability violations would start to occur. Mitigation measures would be required if higher penetration levels are desired.

To maintain system reliability, the bulk power system is expected to operate within a 200-MHz band around the nominal system frequency of 50 Hz under normal conditions. This means the frequency should remain between 49.8 Hz and 50.2 Hz at all times when all transmission assets are in service. Under contingency conditions, the allowed deviation increases to 500 MHz but the frequency is expected to return to the 200-MHz band within 10 minutes. This means the frequency can be as low as 49.5 Hz or as high as 50.5 Hz following the loss of a transmission line, transformer, or generator, but it should return to the accepted 49.8- to 50.2-Hz range within 10 minutes.

# IV. MODELING RESULTS – STEADY STATE ANALYSIS

This section discusses the results of the model simulations for the Base Case and the four solar PV penetration cases. The performance of the system was examined under normal and contingency conditions. Under normal conditions, all transmission lines are assumed to be in operation. Contingency conditions assume at least one major transmission line is out of service.

The results of the steady state analyses are summarized in Tables 4, 5, and 6. Table 4 is a summary of the substation voltage violations observed in all the cases. Table 5 shows the results of the analysis of line loading, and Table 6 compares system losses in the scenarios examined.

Very few violations were observed under both normal and contingency conditions in the steady state analysis. Voltage violations occurred at Bui and Kintampo under normal conditions in Scenario 1. The voltages exceeded the high limit of 1.05 p.u. slightly at both substations. ICF determined that a 30 megavolt-ampere reactive (MVAr) reactor at Bui could resolve all the voltage violations. Under contingency conditions, violations occurred at Sawla, Sunyani, and Techiman in addition to Bui and Kintampo. The 30 MVAr reactor at Bui successfully resolved these violations too.[4]

No voltage violations were observed in any of the other scenarios. The inverters on the solar PV systems are configured to support system voltages. They can produce reactive power to boost system voltages or absorb reactive power to lower system voltages, in line with the assumptions noted above. The higher solar penetration in Scenarios 2, 3, and 4 increases the number of generators in the north that can help control system voltages and ensure voltages remain within reliability criteria limits. Therefore, it is important to ensure that solar PV plants are configured to provide reactive power, which then helps reduce voltage violations in the grid.

No overloads were observed on the monitored lines in the North Zone in any of the scenarios examined. Because of the relatively low demand in the North Zone, the transmission lines are typically lightly loaded. Additional analyses can be done in the future to assess potential overloads, as demand grows over time in the North (and elsewhere across the country).

Table 6 is a summary of total generation, load, and system losses for all scenarios. System losses are also summarized in Figure 4. Base Case losses are 115.8 MW, or 4.09% of load. Transmission system losses are lower in Scenario 1, at 91.2 MW or 3.25% of load. Increasing addition of solar in the north reduces the need to import power over long transmission lines from the south, through Ashanti, to serve load in the north. At the 10% penetration level in Scenario 2, losses are even lower, at 87.8 MW or 3.13% of load. Losses start to increase in Scenario 3, as more solar is added to achieve a 20% penetration level. This is because at this penetration level (assuming total demand is fixed at 2,573 MW) solar dispatch not only displaces imports into the north, and but it also starts to export to load in the south. Losses increase further in Scenario 4. At the 30% penetration, level dispatch from solar in the north is carried over long

[4] A shunt reactor is used to illustrate the ability to mitigate violations. Other mitigation measures should be examined to determine the cost-effective approach.

transmission lines to serve load in the south, reversing the trend observed in the Base Case, but nonetheless increasing losses.

**Table 4: Summary of Substation Voltage Violations for Scenarios Examined**

| Scenario | Normal (N-0) Conditions | | Contingency (N-1) Conditions | |
|---|---|---|---|---|
| | Number of Violations | Mitigation | Number of Violations | Mitigation |
| Base Case | 0 | N/A | 0 | N/A |
| Scenario 1 | 2 | 30 MVAr Reactor at Bui | 5 | 30 MVAr Reactor at Bui |
| Scenario 2 | 0 | N/A | 0 | N/A |
| Scenario 3 | 0 | N/A | 0 | N/A |
| Scenario 4 | 0 | N/A | 0 | N/A |

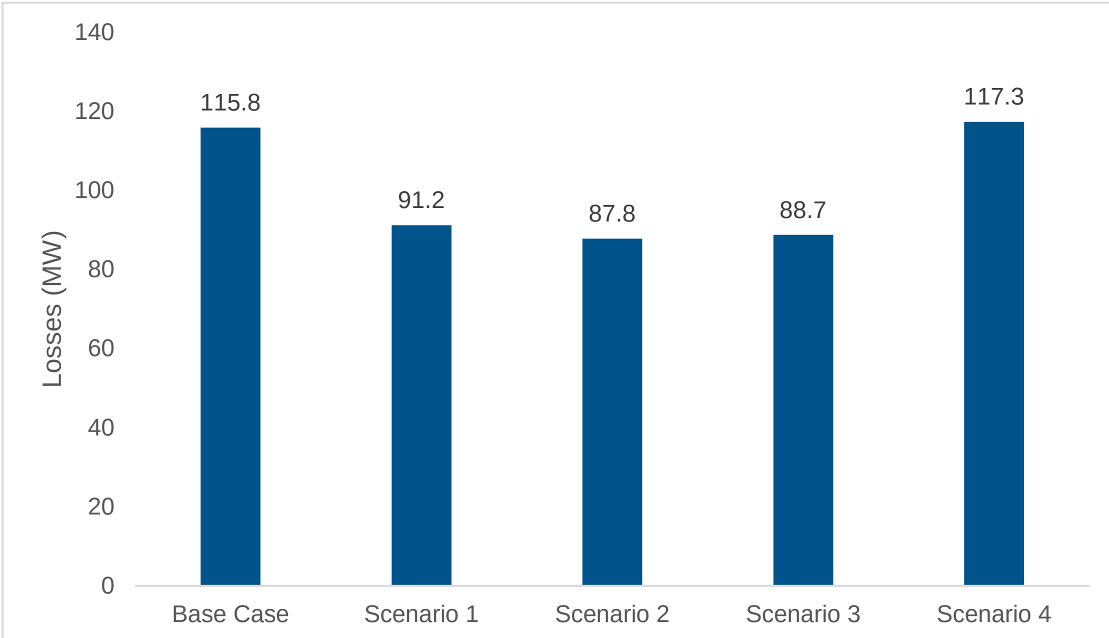
**Table 5: Summary of Line Overloads for Scenarios Examined**

| Scenario | Normal (N-0) Conditions | | Contingency (N-1) Conditions | |
|---|---|---|---|---|
| | Number of Violations | Mitigation | Number of Violations | Mitigation |
| Base Case | 0 | N/A | 0 | N/A |
| Scenario 1 | 0 | N/A | 0 | N/A |
| Scenario 2 | 0 | N/A | 0 | N/A |
| Scenario 3 | 0 | N/A | 0 | N/A |
| Scenario 4 | 0 | N/A | 0 | N/A |

**Table 6: Summary of Generation, Load, and Losses**

| Scenario | Total Generation (MW) | Off-Peak System Load (MW) | Net Interchange (MW) | System Losses (MW) | System Losses (% of Generation) |
|---|---|---|---|---|---|
| Base Case | 2829.5 | 2573.2 | 136.4 | 115.8 | 4.09 |
| Scenario 1 | 2804.3 | 2573.2 | 136.6 | 91.2 | 3.25 |
| Scenario 2 | 2800.9 | 2573.2 | 136.8 | 87.8 | 3.13 |
| Scenario 3 | 2802.0 | 2573.2 | 136.9 | 88.7 | 3.17 |
| Scenario 4 | 2831.5 | 2573.2 | 136.8 | 117.3 | 4.14 |

**Figure 4: Comparison of System Losses**




ICF examined the potential impact of solar generation in northern Ghana on imports of power from generators in the southern part of the country. Because all generators except Bui are located in the south of the country, the north depends on imports from the south to meet its demand. Consistent with the Integrated Power Sector Master Plan that is being developed by ICF's Integrated Resource and Resiliency Planning (IRRP) project, ICF grouped substations in the Brong Ahafo, Northern, Upper East, and Upper West regions together to form the North Zone as shown in Figure 5. The transmission interface between the North Zone and the zones in the south comprises the following transmission lines:

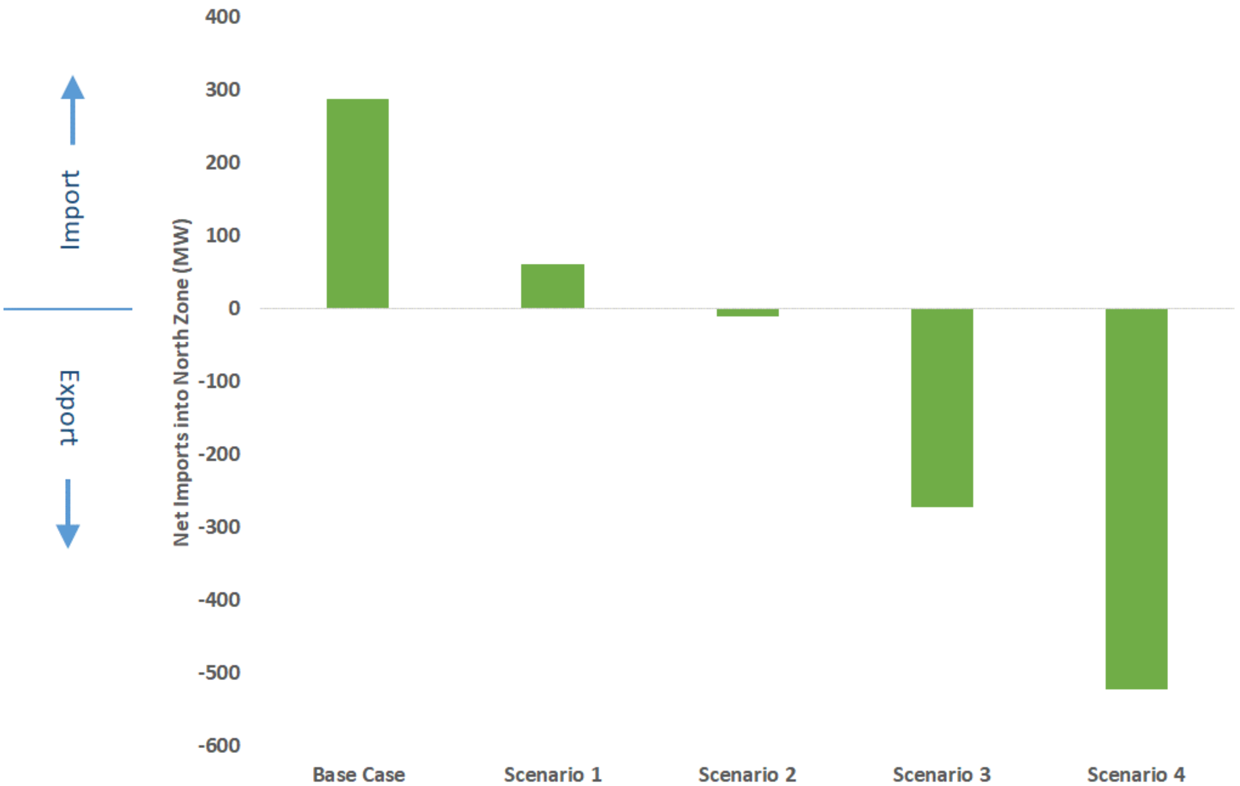
- 161 kV Kumasi (4) to Kenyase (3) Line
- 161 kV Kumasi (4) to Techiman (2) Line
- 161 kV Mim (6) to Juabeso (7) Line
- 161 kV Obuasi (5) to Kenyase (3) Line
- 330 kV Anwomaso (4) to Kintampo (1) Line [5]

[5] Anwomaso is the second bulk supply point (BSP) in Kumasi.

### Figure 5: North Zone of Ghana Bulk Power System


Figure 6 shows the net power flows from south to north in all of the scenarios in the off-peak period. In the Base Case, the North Zone imports approximately 288 MW of power from generators in the south of the country to meet its full off-peak demand. As solar generation becomes increasingly available to serve some of the demand in the North Zone, the North Zone depends less on imports from the south. In Scenario 1, the North Zone imports a net amount of approximately 61 MW, which is down 79% from the Base Case import level. In Scenario 2, Scenario 3, and Scenario 4, the trend reverses. Solar generation at this maximum point (typically between 12 PM and 1 PM) exceeds off-peak demand in the North Zone, and the North Zone begins to export 11 MW, 273 MW, and 523 MW, respectively to serve demand in the southern part of the country. Note that outside of the peak generation times for solar PV, the amount of exports to the south would decrease, and similarly, if the demand in the northern region were to increase, the amount of exports to the south would correspondingly decrease even with maximum solar PV generation.

**Figure 6: Net Power Flows between North Zone and South Areas**




## IV.1. DETAILED RESULTS – BASE CASE

The voltages at key substations in northern Ghana (for system operation under normal conditions) are shown in Table 7. Under normal conditions, all substation voltages are within the reliability limits.

**Table 7: Base Case Substation Voltages Under Normal Conditions**

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) |
|---|---|---|---|
| Techiman 161 kV | 161 | 166.27 | 1.03 |
| Sunyani 161 kV | 161 | 165.09 | 1.03 |
| Tamale 161 kV | 161 | 161.00 | 1.00 |
| Bolgatanga 161 kV | 161 | 158.94 | 0.99 |
| Yendi 161 kV | 161 | 157.94 | 0.98 |
| Sawla 161 kV | 161 | 166.31 | 1.03 |
| Zebilla 161 kV | 161 | 158.56 | 0.98 |
| Bui 161 kV | 161 | 168.24 | 1.04 |
| Buipe 161 kV | 161 | 164.79 | 1.02 |
| Kintampo 161 kV | 161 | 167.35 | 1.04 |
| Wa 161 kV | 161 | 163.75 | 1.02 |

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) |
|---|---|---|---|
| Tumu 161 kV | 161 | 161.11 | 1.00 |
| Bawku 161 kV | 161 | 158.25 | 0.98 |
| Tamale 330 kV | 330 | 337.33 | 1.02 |
| Bolgatanga 330 kV | 330 | 331.41 | 1.00 |
| Bolgatanga 225 kV | 225 | 225.59 | 1.00 |
| Kintampo 330 kV | 330 | 341.20 | 1.03 |

Table 8 shows the loading on key transmission lines in northern Ghana under normal conditions. The power flow on most of the major lines in the north of the country is low relative to the ratings. Line loadings are within approximately 10% of the ratings of the lines. No overloads are observed under normal conditions.

**Table 8: Base Case Line Loading Under Normal Conditions**

| Line Name | Rating (MW) | Loading (% of Rating) |
|---|---|---|
| 161 kV Sunyani to Techiman Line | 244 | 5.55 |
| 161 kV Techiman to Bui Line | 364 | 5.40 |
| 161 kV Techiman to Kintampo Line | 364 | 4.05 |
| 161 kV Sunyani to Bui Line | 364 | 5.53 |
| 161 kV Tamale to Bolgatanga Line | 244 | 1.59 |
| 161 kV Tamale to Yendi Line | 182 | 9.39 |
| 161 kV Tamale to Buipe Line | 364 | 8.54 |
| 161 kV Bolgatanga to Zebilla Line | 182 | 5.59 |
| 161 kV Bolgatanga to Tumu Line | 364 | 5.98 |
| 161 kV Bui to Sawla Line | 182 | 10.57 |
| 161 kV Wa to Sawla Line | 182 | 8.30 |
| 161 kV Bawku to Zebilla Line | 182 | 2.87 |
| 161 kV Kintampo to Bui Line | 364 | 4.41 |
| 161 kV Kintampo to Buipe Line | 364 | 8.95 |
| 161 kV Wa to Tumu Line | 182 | 0.70 |
| 330 kV Tamale to Bolgatanga Line | 1,000 | 3.96 |
| 330 kV Tamale to Kintampo Line | 1,000 | 10.80 |

Total generation and losses are shown in Table 9. The system losses are just slightly higher than the limit of 4% required by the Public Utilities Regulatory Commission (PURC). Because the Bui Plant is assumed to be offline during the off-peak period, all of the demand in the north is served by generation from the south. Losses increase due to power traveling over long transmission lines to serve demand in the north.

**Table 9: Base Case Generation, Load, and Losses**

| Total Generation (MW) | Off-Peak System Load (MW) | Net Interchange (MW) | Losses (MW) | Losses (% of Generation) |
|---|---|---|---|---|
| 2,829.5 | 2,573.2 | 136.4 | 115.8 | 4.09 |

Substation voltages and line loadings remain within limits under contingency conditions. Substation voltages are shown in Table 10. Only the highest voltage and the associated contingency are shown.

**Table 10: Base Case Substation Voltages Under Contingency Conditions**

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Techiman 161 kV | 161 | 167.07 | 1.04 | 161 kV Kintampo-Buipe Line |
| Sunyani 161 kV | 161 | 165.79 | 1.03 | 161 kV Kintampo-Buipe Line |
| Tamale 161 kV | 161 | 161.00 | 1.00 | 161 kV Kintampo-Buipe Line |
| Bolga 161 kV | 161 | 162.77 | 1.01 | 330 kV Tamale-Kin Line |
| Yendi 161 kV | 161 | 157.94 | 0.98 | 330 kV Tamale-Kin Line |
| Sawla 161 kV | 161 | 169.79 | 1.05 | 161 kV Sawla-Wa Line |
| Zebilla 161 kV | 161 | 162.43 | 1.01 | 330 kV Tamale-Kin Line |
| Bui 161 kV | 161 | 169.07 | 1.05 | 161 kV Kintampo-Buipe Line |
| Buipe 161 kV | 161 | 164.88 | 1.02 | 161 kV Sawla-Wa Line |
| Kintampo 161 kV | 161 | 168.31 | 1.05 | 161 kV Kintampo-Buipe Line |
| Wa 161 kV | 161 | 164.66 | 1.02 | 330 kV Tamale-Kin Line |
| Tumu 161 kV | 161 | 163.73 | 1.02 | 330 kV Tamale-Kin Line |
| Bawku 161 kV | 161 | 162.14 | 1.01 | 330 kV Tamale-Kin Line |
| Tamale 330 kV | 330 | 338.2 | 1.02 | 330 kV Tamale-Bolga Line |
| Bolga 330 kV | 330 | 336.01 | 1.02 | 330 kV Tamale-Kin Line |
| Bolga 225 kV | 225 | 228.23 | 1.01 | 330 kV Tamale-Kin Line |
| Kintampo 330 kV | 330 | 342.21 | 1.04 | 161 kV Kintampo-Buipe Line |

Table 11 shows the loading on key transmission lines in northern Ghana under contingency conditions. The power flow on each line changes with the contingent element, but only the highest loading on each line and the contingency that causes the highest loading are shown in the table. No overloads are observed under contingency conditions.

**Table 11: Base Case Line Loading Under Contingency Conditions**

| Monitored Line | Rating (MW) | Loading (% of Rating) | Contingent Element |
|---|---|---|---|
| 161 kV Sunyani to Techiman Line | 244 | 8.26 | 161 kV Bui-Sunyani Line |
| 161 kV Techiman to Bui Line | 364 | 6.75 | 330 kV Tamale-Kin Line |
| 161 kV Techiman to Kintampo Line | 364 | 5.37 | 161 kV Bui-Sunyani Line |
| 161 kV Sunyani to Bui Line | 364 | 6.1 | 330 kV Tamale-Kin Line |
| 161 kV Tamale to Bolgatanga Line | 244 | 12.81 | 330 kV Tamale-Bolga Line |
| 161 kV Tamale to Yendi Line | 182 | 9.39 | 330 kV Tamale-Kin Line |
| 161 kV Tamale to Buipe Line | 364 | 24.24 | 330 kV Tamale-Kin Line |
| 161 kV Bolgatanga to Zebilla Line | 182 | 5.91 | 161 kV Bui-Sunyani Line |
| 161 kV Bolgatanga to Tumu Line | 364 | 10.57 | 161 kV Bui-Sunyani Line |
| 161 kV Bui to Sawla Line | 182 | 20.26 | 330 kV Tamale-Kin Line |
| 161 kV Wa to Sawla Line | 182 | 18.36 | 330 kV Tamale-Kin Line |
| 161 kV Bawku to Zebilla Line | 182 | 3.95 | 161 kV Bui-Sunyani Line |
| 161 kV Kintampo to Bui Line | 364 | 9.94 | 161 kV Sawla-Wa Line |
| 161 kV Kintampo to Buipe Line | 364 | 26.47 | 330 kV Tamale-Kin Line |
| 161 kV Wa to Tumu | 182 | 11 | 330 kV Tamale-Kin Line |
| 330 kV Tamale to Bolgatanga Line | 1000 | 13.15 | 161 kV Kin-Buipe Line |
| 330 kV Tamale to Kintampo Line | 1000 | 8.26 | 161 kV Bui-Sunyani Line |

## IV.2. Scenario 1 Results – Integration of Planned Solar PV Generation

In this scenario, up to 235 MW of solar PV generation that have requested studies or are currently under study by GRIDCo are interconnected and dispatched at substations in the northern part of the country.

Table 12 shows the voltages at key substations in northern Ghana (for system operation under normal conditions). Under normal conditions, voltages at most of the substations remain within the reliability limits. However, voltages at Bui and Kintampo exceed the 1.05 p.u. limit slightly. ICF's analysis showed that installation of a 30-MVAr reactor at Bui could resolve the violations observed in this scenario.

**Table 12: Scenario 1 Substation Voltages Under Normal Conditions**

| Substation Name | Voltage Rating (kV) | Substation Voltages | | Substation Voltages with 30 MVAr Reactor | |
|---|---|---|---|---|---|
| | | kV | p.u. | kV | p.u. |
| Techiman 161 kV | 161 | 168.20 | 1.04 | 165.48 | 1.03 |
| Sunyani 161 kV | 161 | 167.42 | 1.04 | 164.79 | 1.02 |
| Tamale 161 kV | 161 | 161.18 | 1.00 | 160.57 | 1.00 |
| Bolgatanga 161 kV | 161 | 160.20 | 1.00 | 159.55 | 0.99 |
| Yendi 161 kV | 161 | 158.12 | 0.98 | 157.49 | 0.98 |
| Sawla 161 kV | 161 | 167.39 | 1.04 | 164.05 | 1.02 |
| Zebilla 161 kV | 161 | 160.75 | 1.00 | 160.40 | 1.00 |
| Bui 161 kV | 161 | 169.37 | 1.05 | 165.13 | 1.03 |
| Buipe 161 kV | 161 | 165.29 | 1.03 | 163.81 | 1.02 |
| Kintampo 161 kV | 161 | 168.78 | 1.05 | 166.31 | 1.03 |
| Wa 161 kV | 161 | 164.94 | 1.02 | 162.27 | 1.01 |
| Tumu 161 kV | 161 | 162.00 | 1.01 | 160.68 | 1.00 |
| Bawku 161 kV | 161 | 160.44 | 1.00 | 160.09 | 0.99 |
| Tamale 330 kV | 330 | 340.76 | 1.03 | 338.69 | 1.03 |
| Bolgatanga 330 kV | 330 | 335.12 | 1.02 | 333.40 | 1.01 |
| Bolgatanga 225 kV | 225 | 228.42 | 1.02 | 227.26 | 1.01 |
| Kintampo 330 kV | 330 | 346.03 | 1.05 | 342.88 | 1.04 |

Table 13 shows the loading on key transmission lines in northern Ghana under normal conditions. Similar to the Base Case, the power flow on most of the major lines in the north of the country is low relative to the ratings. Line loadings are within approximately 15% of the ratings of the lines. No overloads are observed under normal conditions.

**Table 13: Scenario 1 Line Loading Under Normal Conditions**

| Line Name | Rating (MW) | Loading (% of Rating) |
|---|---|---|
| 161 kV Sunyani to Techiman Line | 244 | 12.97 |
| 161 kV Techiman to Bui Line | 364 | 7.63 |
| 161 kV Techiman to Kintampo Line | 364 | 8.73 |
| 161 kV Sunyani to Bui Line | 364 | 10.20 |
| 161 kV Tamale to Yendi Line | 182 | 9.39 |
| 161 kV Bolgatanga to Tumu Line | 364 | 4.29 |
| 161 kV Wa to Sawla Line | 182 | 8.74 |
| 161 kV Bawku to Zebilla Line | 182 | 2.88 |

| Line Name | Rating (MW) | Loading (% of Rating) |
|---|---|---|
| 161 kV Kintampo to Bui Line | 364 | 6.14 |
| 161 kV Kintampo to Buipe Line | 364 | 8.64 |
| 330 kV Tamale to Bolgatanga Line | 1000 | 0.80 |
| 330 kV Tamale to Kintampo Line | 1000 | 7.27 |

Total generation and losses are shown in Table 14. The system losses are lower than that in the Base Case, and below the limit of 4% required by PURC. The solar PV generation in the north displaces imports from the south and reduces the need for generation over long transmission lines, which reduces system losses.

**Table 14: Scenario 1 Generation, Load, and Losses**

| Total Generation (MW) | Off-Peak System Load (MW) | Net Interchange (MW) | Losses (MW) | Losses (% of Generation) |
|---|---|---|---|---|
| 2,804.3 | 2,573.2 | 136.6 | 91.2 | 3.25 |

Under contingency conditions, voltages are expected to remain within a 10% band of the nominal values, or between 0.90 p.u. and 1.10 p.u. The voltages at all of the monitored substations remain within the reliability limits under contingency conditions. Substation voltages are shown in Table 15. Only the highest voltage and the associated contingency are shown.

**Table 15: Scenario 1 Substation Voltages Under Contingency Conditions**

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Techiman 161 kV | 161 | 169.81 | 1.05 | 161 kV Kintampo-Buipe Line |
| Sunyani 161 kV | 161 | 168.78 | 1.05 | 161 kV Kintampo-Buipe Line |
| Tamale 161 kV | 161 | 161.15 | 1.00 | 161 kV Sawla-Wa Line |
| Bolga 161 kV | 161 | 160.35 | 1.00 | 161 kV Kintampo-Buipe Line |
| Yendi 161 kV | 161 | 158.09 | 0.98 | 161 kV Sawla-Wa Line |
| Sawla 161 kV | 161 | 169.62 | 1.05 | 161 kV Sawla-Wa Line |
| Zebilla 161 kV | 161 | 160.78 | 1.00 | 161 kV Kintampo-Buipe Line |
| Bui 161 kV | 161 | 171.08 | 1.06 | 161 kV Kintampo-Buipe Line |
| Buipe 161 kV | 161 | 165.25 | 1.03 | 161 kV Sawla-Wa Line |
| Kintampo 161 kV | 161 | 170.80 | 1.06 | 161 kV Kintampo-Buipe Line |
| Wa 161 kV | 161 | 165.98 | 1.03 | 161 kV Kintampo-Buipe Line |
| Tumu 161 kV | 161 | 162.45 | 1.01 | 161 kV Kintampo-Buipe Line |
| Bawku 161 kV | 161 | 160.48 | 1.00 | 161 kV Kintampo-Buipe Line |
| Tamale 330 kV | 330 | 341.26 | 1.03 | 161 kV Kintampo-Buipe Line |
| Bolga 330 kV | 330 | 335.54 | 1.02 | 161 kV Kintampo-Buipe Line |

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Bolga 225 kV | 225 | 228.71 | 1.02 | 161 kV Kintampo-Buipe Line |
| Kintampo 330 kV | 330 | 347.99 | 1.05 | 161 kV Kintampo-Buipe Line |

Table 16 shows the loading on key transmission lines in northern Ghana under contingency conditions. The power flow on each line changes with the contingent element, but only the highest loading on each line and the contingency that causes the highest loading are shown in the table. No overloads are observed under contingency conditions.

**Table 16: Scenario 1 Line Loading Under Contingency Conditions**

| Monitored Line | Rating (MW) | Loading (% of Rating) | Contingent Element |
|---|---|---|---|
| 161 kV Bawku to Zebilla | 182 | 2.88 | 161 kV Kintampo-Buipe Line |
| 161 kV Bolgatanga to Tumu | 364 | 7.95 | 330 kV Tamale-Bolga Line |
| 161 kV Bui to Kintampo | 364 | 10.81 | 161 kV Bui-Sunyani Line |
| 161 kV Buipe to Kintampo | 364 | 7.73 | 161 kV Bui-Sunyani Line |
| 161 kV Sunyani to Bui | 364 | 10.95 | 161 kV Sawla-Wa Line |
| 161 kV Sunyani to Techiman | 244 | 21.91 | 161 kV Bui-Sunyani Line |
| 161 kV Tamale to Yendi | 182 | 9.47 | 330 kV Tamale-Kin Line |
| 161 kV Techiman to Bui | 364 | 12.09 | 161 kV Bui-Sunyani Line |
| 161 kV Techiman to Kintampo | 364 | 11.11 | 161 kV Bui-Sunyani Line |
| 161 kV Wa to Sawla | 182 | 10.52 | 330 kV Tamale-Bolga Line |
| 330 kV Tamale to Bolgatanga | 1000 | 1.51 | 161 kV Sawla-Wa Line |
| 330 kV Tamale to Kintampo | 1000 | 8.30 | 161 kV Kintampo-Buipe Line |

## IV.3. Scenario 2 Results – Integration of 10% Penetration of Solar PV Generation

This scenario is similar to Scenario 1, but with a total of 280 MW of solar PV interconnected to the GRIDCo system to increase the penetration level to 10%. In addition to the 235 MW of solar PV from Scenario 1, incremental capacities of 50 MW and 25 MW are connected at Kintampo and Tumu, respectively.

Table 17 shows the voltages at key substations in northern Ghana (for system operation under normal conditions). Under normal conditions, voltages at all of the substations remain within the reliability limits. This is because the solar PV generation is configured to provide voltage support in line with the Ghana RE Grid Code.

**Table 17: Scenario 2 Substation Voltages Under Normal Conditions**

| Substation Name | Voltage Rating (kV) | Substation Voltages | |
|---|---|---|---|
| | | kV | p.u. |
| Techiman 161 kV | 161 | 165.91 | 1.03 |
| Sunyani 161 kV | 161 | 165.06 | 1.03 |
| Tamale 161 kV | 161 | 160.52 | 1.00 |
| Bolgatanga 161 kV | 161 | 159.45 | 0.99 |
| Yendi 161 kV | 161 | 157.44 | 0.98 |
| Sawla 161 kV | 161 | 165.43 | 1.03 |
| Zebilla 161 kV | 161 | 160.30 | 1.00 |
| Bui 161 kV | 161 | 167.00 | 1.04 |
| Buipe 161 kV | 161 | 163.90 | 1.02 |
| Kintampo 161 kV | 161 | 166.52 | 1.03 |
| Wa 161 kV | 161 | 163.38 | 1.01 |
| Tumu 161 kV | 161 | 161.13 | 1.00 |
| Bawku 161 kV | 161 | 159.99 | 0.99 |
| Tamale 330 kV | 330 | 338.55 | 1.03 |
| Bolgatanga 330 kV | 330 | 333.39 | 1.01 |
| Bolgatanga 225 kV | 225 | 227.32 | 1.01 |
| Kintampo 330 kV | 330 | 342.53 | 1.04 |

Table 18 shows the loading on key transmission lines in northern Ghana under normal conditions. Similar to the Base Case, the power flow on most of the major lines in the north of the country is low relative to the ratings. Line loadings are within approximately 20% of the ratings of the lines. No overloads are observed under normal conditions.

**Table 18: Scenario 2 Line Loading Under Normal Conditions**

| Line Name | Rating (MW) | Loading (% of Rating) |
|---|---|---|
| 161 kV Sunyani to Techiman Line | 244 | 16.34 |
| 161 kV Techiman to Bui Line | 364 | 8.78 |
| 161 kV Techiman to Kintampo Line | 364 | 13.50 |
| 161 kV Sunyani to Bui Line | 364 | 12.17 |
| 161 kV Tamale to Yendi Line | 182 | 9.40 |
| 161 kV Bolgatanga to Tumu Line | 364 | 8.10 |
| 161 kV Wa to Sawla Line | 182 | 5.53 |

| Line Name | Rating (MW) | Loading (% of Rating) |
|---|---|---|
| 161 kV Bawku to Zebilla Line | 182 | 2.87 |
| 161 kV Kintampo to Bui Line | 364 | 4.80 |
| 161 kV Kintampo to Buipe Line | 364 | 7.00 |
| 330 kV Tamale to Bolgatanga Line | 1000 | 1.21 |
| 330 kV Tamale to Kintampo Line | 1000 | 6.56 |

Total generation and losses are shown in Table 19. The system losses are lower than the limit of 4% required by PURC. This is also lower than the losses in Scenario 1 because the higher solar PV generation in the north reduces the need for imports over long distances from the south.

**Table 19: Scenario 2 Generation, Load, and Losses**

| Total Generation (MW) | Off-Peak System Load (MW) | Net Interchange (MW) | Losses (MW) | Losses (% of Generation) |
|---|---|---|---|---|
| 2,800.9 | 2,573.2 | 136.8 | 87.8 | 3.13 |

Substation voltages and line loadings remain within limits under contingency conditions. Substation voltages are shown in Table 20. Only the highest voltage and the associated contingency are shown.

**Table 20: Scenario 2 Substation Voltages Under Contingency Conditions**

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Techiman 161 kV | 161 | 167.18 | 1.04 | 161 kV Kin-Buipe Line |
| Sunyani 161 kV | 161 | 166.21 | 1.03 | 161 kV Kin-Buipe Line |
| Tamale 161 kV | 161 | 160.58 | 1.00 | 161 kV Sawla-Wa Line |
| Bolga 161 kV | 161 | 159.58 | 0.99 | 161 kV Sawla-Wa Line |
| Yendi 161 kV | 161 | 157.51 | 0.98 | 161 kV Sawla-Wa Line |
| Sawla 161 kV | 161 | 167.39 | 1.04 | 161 kV Sawla-Wa Line |
| Zebilla 161 kV | 161 | 160.43 | 1.00 | 161 kV Sawla-Wa Line |
| Bui 161 kV | 161 | 168.33 | 1.05 | 161 kV Kin-Buipe Line |
| Buipe 161 kV | 161 | 164.00 | 1.02 | 161 kV Sawla-Wa Line |
| Kintampo 161 kV | 161 | 168.07 | 1.04 | 161 kV Kin-Buipe Line |
| Wa 161 kV | 161 | 163.98 | 1.02 | 161 kV Kin-Buipe Line |
| Tumu 161 kV | 161 | 161.17 | 1.00 | 161 kV Kin-Buipe Line |
| Bawku 161 kV | 161 | 160.13 | 0.99 | 161 kV Sawla-Wa Line |
| Tamale 330 kV | 330 | 339.00 | 1.03 | 161 kV Kin-Buipe Line |

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Bolga 330 kV | 330 | 333.73 | 1.01 | 161 kV Kin-Buipe Line |
| Bolga 225 kV | 225 | 227.56 | 1.01 | 161 kV Kin-Buipe Line |
| Kintampo 330 kV | 330 | 344.07 | 1.04 | 161 kV Kin-Buipe Line |

Table 21 shows the loading on key transmission lines in northern Ghana under contingency conditions. The power flow on each line changes with the contingent element, but only the highest loading on each line and the contingency that causes the highest loading are shown in the table. No overloads are observed under contingency conditions.

**Table 21: Scenario 2 Line Loading Under Contingency Conditions**

| Monitored Line | Rating (MW) | Loading (% of Rating) | Contingent Element |
|---|---|---|---|
| 161 kV Bawku to Zebilla Line | 182 | 2.87 | 161 kV Bui-Sunyani Line |
| 161 kV Bolgatanga to Tumu Line | 364 | 11.37 | 330 kV Tamale-Bolga Line |
| 161 kV Kintampo to Bui Line | 364 | 9.99 | 161 kV Bui-Sunyani Line |
| 161 kV Kintampo to Buipe Line | 364 | 9.05 | 330 kV Tamale-Kin Line |
| 161 kV Sunyani to Bui Line | 364 | 12.66 | 161 kV Sawla-Wa Line |
| 161 kV Sunyani to Techiman Line | 244 | 27.13 | 161 kV Bui-Sunyani Line |
| 161 kV Tamale to PV Collector Line | 244 | 19.15 | 330 kV Tamale-Bolga Line |
| 161 kV Tamale to Yendi Line | 182 | 9.46 | 330 kV Tamale-Kin Line |
| 161 kV Techiman to Bui Line | 364 | 14.27 | 161 kV Bui-Sunyani Line |
| 161 kV Techiman to Kintampo Line | 364 | 16.30 | 161 kV Bui-Sunyani Line |
| 161 kV Wa to Sawla Line | 182 | 6.65 | 161 kV Bui-Sunyani Line |
| 330 kV Tamale to Bolgatanga Line | 1000 | 1.77 | 330 kV Tamale-Kin Line |
| 330 kV Tamale to Kintampo Line | 1000 | 7.50 | 161 kV Kin-Buipe Line |

## IV.4. Scenario 3 Results – Integration of 20% Penetration of Solar PV Generation

In this scenario, additional solar PV resources are connected to increase the penetration level to 20% of generation. This doubles the solar PV generation from 280 MW in Scenario 2 to 560 MW. Distribution of the incremental 280 MW of solar PV is as follows:

- 100 MW at Techiman
- 50 MW at Kintampo
- 50 MW at Bolgatanga

- 30 MW at a GRIDCo proposed solar PV Collector Station[6]
- 25 MW at Zebilla
- 25 MW at Tumu

The voltages at key substations in northern Ghana (for system operation under normal conditions) are shown in Table 22. Under normal conditions, voltages at all of the substations remain within the reliability limits. The lowest voltage, 0.97 p.u. at Yendi, is within the 5% band required under normal conditions. The solar PV resources are configured to provide voltage support in line with the Ghana RE Grid Code.

**Table 22: Scenario 3 Substation Voltages Under Normal Conditions**

| Substation Name | Voltage Rating (kV) | Substation Voltages | |
|---|---|---|---|
| | | kV | p.u. |
| Techiman 161 kV | 161 | 162.39 | 1.01 |
| Sunyani 161 kV | 161 | 162.06 | 1.01 |
| Tamale 161 kV | 161 | 159.57 | 0.99 |
| Bolgatanga 161 kV | 161 | 159.67 | 0.99 |
| Yendi 161 kV | 161 | 156.46 | 0.97 |
| Sawla 161 kV | 161 | 162.75 | 1.01 |
| Zebilla 161 kV | 161 | 161.02 | 1.00 |
| Bui 161 kV | 161 | 163.54 | 1.02 |
| Buipe 161 kV | 161 | 162.01 | 1.01 |
| Kintampo 161 kV | 161 | 163.30 | 1.01 |
| Wa 161 kV | 161 | 161.62 | 1.00 |
| Tumu 161 kV | 161 | 161.11 | 1.00 |
| Bawku 161 kV | 161 | 160.72 | 1.00 |
| Tamale 330 kV | 330 | 336.42 | 1.02 |
| Bolgatanga 330 kV | 330 | 332.89 | 1.01 |
| Bolgatanga 225 kV | 225 | 227.23 | 1.01 |
| Kintampo 330 kV | 330 | 338.68 | 1.03 |

Table 23 shows the loading on key transmission lines in northern Ghana under normal conditions. Similar to the Base Case, the power flow on most of the major lines in the north of

[6] ICF understands that GRIDCo is strategically facilitating energy Collector Stations to proactively accommodate RE connections. (See https://www.esi-africa.com/wp-content/uploads/2016/05/Bernard-Modey-1.pdf, accessed April 18th, 2018.)

the country is low relative to the ratings. Line loadings are within approximately 20% of the ratings of the lines. No overloads are observed under normal conditions.

**Table 23: Scenario 3 Line Loading Under Normal Conditions**

| Line Name | Rating (MW) | Loading (% of Rating) |
|---|---|---|
| 161 kV Sunyani to Techiman Line | 244 | 33.31 |
| 161 kV Techiman to Bui Line | 364 | 8.15 |
| 161 kV Techiman to Kintampo Line | 364 | 14.09 |
| 161 kV Sunyani to Bui Line | 364 | 17.62 |
| 161 kV Tamale to Yendi Line | 182 | 9.41 |
| 161 kV Bolgatanga to Tumu Line | 364 | 10.93 |
| 161 kV Wa to Sawla Line | 182 | 2.60 |
| 161 kV Bawku to Zebilla Line | 182 | 2.88 |
| 161 kV Kintampo to Bui Line | 364 | 4.37 |
| 161 kV Kintampo to Buipe Line | 364 | 7.92 |
| 330 kV Tamale to Bolgatanga Line | 1000 | 7.29 |
| 330 kV Tamale to Kintampo Line | 1000 | 11.64 |

Total generation and losses are shown in Table 24. The system losses are lower than the limit of 4% required by PURC, but slightly higher than the losses in Scenario 2. At the 20% penetration level, not only does solar generation displace imports from generation in the south but excess generation in the north is exported to meet some of the demand in the south. The north-to-south flows over long transmission lines start to increase losses relative to Scenario 2.

**Table 24: Scenario 3 Generation, Load, and Losses**

| Total Generation (MW) | Off-Peak System Load (MW) | Net Interchange (MW) | Losses (MW) | Losses (% of Generation) |
|---|---|---|---|---|
| 2,802.0 | 2,573.2 | 136.9 | 88.7 | 3.17 |

Substation voltages and line loadings remain within limits under contingency conditions. Substation voltages are shown in Table 25. Only the highest voltage and the associated contingency are shown.

**Table 25: Scenario 3 Substation Voltages Under Contingency Conditions**

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Techiman 161 kV | 161 | 163.89 | 1.02 | 161 kV Kin-Buipe Line |
| Sunyani 161 kV | 161 | 163.75 | 1.02 | 161 kV Kin-Buipe Line |
| Tamale 161 kV | 161 | 159.76 | 0.99 | 161 kV Sawla-Wa Line |

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Bolga 161 kV | 161 | 159.74 | 0.99 | 161 kV Kin-Buipe Line |
| Yendi 161 kV | 161 | 156.65 | 0.97 | 161 kV Sawla-Wa Line |
| Sawla 161 kV | 161 | 164.70 | 1.02 | 161 kV Sawla-Wa Line |
| Zebilla 161 kV | 161 | 161.02 | 1.00 | 161 kV Sawla-Wa Line |
| Bui 161 kV | 161 | 165.01 | 1.02 | 161 kV Kin-Buipe Line |
| Buipe 161 kV | 161 | 162.54 | 1.01 | 161 kV Sawla-Wa Line |
| Kintampo 161 kV | 161 | 164.81 | 1.02 | 161 kV Kin-Buipe Line |
| Wa 161 kV | 161 | 162.21 | 1.01 | 161 kV Kin-Buipe Line |
| Tumu 161 kV | 161 | 161.14 | 1.00 | 161 kV Kin-Buipe Line |
| Bawku 161 kV | 161 | 160.72 | 1.00 | 161 kV Sawla-Wa Line |
| Tamale 330 kV | 330 | 337.05 | 1.02 | 161 kV Sawla-Wa Line |
| Bolga 330 kV | 330 | 333.29 | 1.01 | 161 kV Kin-Buipe Line |
| Bolga 225 kV | 225 | 227.50 | 1.01 | 161 kV Kin-Buipe Line |
| Kintampo 330 kV | 330 | 340.31 | 1.03 | 161 kV Kin-Buipe Line |

Table 26 shows the loading on key transmission lines in northern Ghana under contingency conditions. The power flow on each line changes with the contingent element, but only the highest loading on each line and the contingency that causes the highest loading are shown in the table. No overloads are observed under contingency conditions.

**Table 26: Scenario 3 Line Loading Under Contingency Conditions**

| Monitored Line | Rating (MW) | Loading (% of Rating) | Contingent Element |
|---|---|---|---|
| 161 kV Bawku to Zebilla Line | 182 | 2.88 | 161 kV Bui-Sunyani Line |
| 161 kV Bolgatanga to Tumu | 364 | 11.99 | 161 kV Sawla-Wa Line |
| 161 kV Kintampo to Bui Line | 364 | 11.44 | 161 kV Bui-Sunyani Line |
| 161 kV Kintampo to Buipe Line | 364 | 26.06 | 330 kV Tamale-Kin Line |
| 161 kV Sunyani to Bui Line | 364 | 19.27 | 330 kV Tamale-Kin Line |
| 161 kV Sunyani to Techiman | 244 | 49.08 | 161 kV Bui-Sunyani Line |
| 161 kV Tamale to Yendi Line | 182 | 9.44 | 330 kV Tamale-Kin Line |
| 161 kV Techiman to Bui Line | 364 | 16.15 | 161 kV Bui-Sunyani Line |
| 161 kV Techiman to Kintampo | 364 | 18.17 | 161 kV Bui-Sunyani Line |
| 161 kV Wa to Sawla Line | 182 | 12.49 | 330 kV Tamale-Kin Line |
| 330 kV Tamale to Bolgatanga Line | 1000 | 7.57 | 161 kV Sawla-Wa Line |
| 330 kV Tamale to Kintampo Line | 1000 | 13.76 | 161 kV Kin-Buipe Line |

## IV.5. Scenario 4 Results – Integration of 30% Penetration of Solar PV Generation

Solar PV penetration is increased to 30% in this scenario. A total of 840 MW of solar PV generation is connected to the GRIDCo system. The incremental 280 MW over the generation in Scenario 3 are connected at three substations—150 MW at Bui, 70 MW at Buipe, 60 MW at Wa.

The voltages at key substations in northern Ghana (for system operation under normal conditions) are shown in Table 27. Under normal conditions, voltages at all of the substations remain within the reliability limits. The lowest voltage, 0.97 p.u. at Yendi, is within the 5% band required under normal conditions. The solar PV resources are configured to provide voltage support in line with the Ghana RE Grid Code.

**Table 27: Scenario 4 Substation Voltages Under Normal Conditions**

| Substation Name | Voltage Rating (kV) | Substation Voltages | |
|---|---|---|---|
| | | kV | p.u. |
| Techiman 161 kV | 161 | 160.96 | 1.00 |
| Sunyani 161 kV | 161 | 159.62 | 0.99 |
| Tamale 161 kV | 161 | 159.11 | 0.99 |
| Bolgatanga 161 kV | 161 | 158.80 | 0.99 |
| Yendi 161 kV | 161 | 155.97 | 0.97 |
| Sawla 161 kV | 161 | 161.19 | 1.00 |
| Zebilla 161 kV | 161 | 160.93 | 1.00 |
| Bui 161 kV | 161 | 161.24 | 1.00 |
| Buipe 161 kV | 161 | 161.21 | 1.00 |
| Kintampo 161 kV | 161 | 161.14 | 1.00 |
| Wa 161 kV | 161 | 161.39 | 1.00 |
| Tumu 161 kV | 161 | 160.97 | 1.00 |
| Bawku 161 kV | 161 | 160.62 | 1.00 |
| Tamale 330 kV | 330 | 333.55 | 1.01 |
| Bolgatanga 330 kV | 330 | 330.70 | 1.00 |
| Bolgatanga 225 kV | 225 | 225.94 | 1.00 |
| Kintampo 330 kV | 330 | 333.77 | 1.01 |

Table 28 shows the loading on key transmission lines in northern Ghana under normal conditions. Similar to the Base Case, the power flow on most of the major lines in the north of the country is low relative to the ratings. Line loadings are within approximately 30% of the ratings of the lines. No overloads are observed under normal conditions.

**Table 28: Scenario 4 Line Loading Under Normal Conditions**

| Line Name | Rating (MW) | Loading (% of Rating) |
|---|---|---|
| 161 kV Sunyani to Techiman Line | 244 | 41.58 |
| 161 kV Techiman to Bui Line | 364 | 23.42 |
| 161 kV Techiman to Kintampo Line | 364 | 20.19 |
| 161 kV Sunyani to Bui Line | 364 | 31.42 |
| 161 kV Tamale to Yendi Line | 182 | 9.42 |
| 161 kV Tamale to PV Collector Line | 244 | 33.53 |
| 161 kV Tamale to Buipe Line | 364 | 20.69 |
| 161 kV Bolgatanga to Tumu Line | 364 | 19.99 |
| 161 kV Bolgatanga to Zebillla Line | 182 | 20.23 |
| 161 kV Bolgatanga to PV Collector Line | 244 | 6.25 |
| 161 kV Wa to Sawla Line | 182 | 16.07 |
| 161 kV Bawku to Zebilla Line | 182 | 2.88 |
| 161 kV Kintampo to Bui Line | 364 | 20.34 |
| 161 kV Bui to Sawla Line | 182 | 41.19 |
| 161 kV Kintampo to Buipe Line | 364 | 12.81 |
| 161 kV Wa to Tumu Line | 182 | 19.91 |
| 330 kV Tamale to Bolgatanga Line | 1000 | 9.53 |
| 330 kV Tamale to Kintampo Line | 1000 | 17.75 |

Total generation and losses are shown in Table 29. The system losses are slightly higher than the limit of 4% required by PURC. At the 30% penetration level, solar generation displaces imports from generation in the south, and generation in excess of the demand in the north is exported to meet some of the demand in the south. The north-to-south flows over long transmission lines increase losses relative to other scenarios.

**Table 29: Scenario 4 Generation, Load, and Losses**

| Total Generation (MW) | Off-Peak System Load (MW) | Net Interchange (MW) | Losses (MW) | Losses (% of Generation) |
|---|---|---|---|---|
| 2,831.5 | 2,573.2 | 136.8 | 117.3 | 4.14 |

Substation voltages and line loadings remain within limits under contingency conditions. Substation voltages are shown in Table 30. Only the highest voltage and the associated contingency are shown.

**Table 30: Scenario 4 Substation Voltages Under Contingency Conditions**

| Substation Name | Voltage Rating (kV) | Voltage (kV) | Voltage (p.u.) | Contingent Element |
|---|---|---|---|---|
| Techiman 161 kV | 161 | 160.98 | 1.00 | 161 kV Sawla-Wa Line |
| Sunyani 161 kV | 161 | 159.73 | 0.99 | 161 kV Sawla-Wa Line |
| Tamale 161 kV | 161 | 159.01 | 0.99 | 161 kV Bui-Sunyani Line |
| Bolga 161 kV | 161 | 158.79 | 0.99 | 330 kV Tamale-Kin Line |
| Yendi 161 kV | 161 | 155.87 | 0.97 | 161 kV Bui-Sunyani Line |
| Sawla 161 kV | 161 | 161.21 | 1.00 | 161 kV Bui-Sunyani Line |
| Zebilla 161 kV | 161 | 160.92 | 1.00 | 330 kV Tamale-Kin Line |
| Bui 161 kV | 161 | 161.34 | 1.00 | 161 kV Sawla-Wa Line |
| Buipe 161 kV | 161 | 161.22 | 1.00 | 161 kV Sawla-Wa Line |
| Kintampo 161 kV | 161 | 161.15 | 1.00 | 161 kV Kin-Buipe Line |
| Wa 161 kV | 161 | 161.39 | 1.00 | 161 kV Bui-Sunyani Line |
| Tumu 161 kV | 161 | 161.05 | 1.00 | 330 kV Tamale-Kin Line |
| Bawku 161 kV | 161 | 160.62 | 1.00 | 330 kV Tamale-Kin Line |
| Tamale 330 kV | 330 | 333.08 | 1.01 | 161 kV Bui-Sunyani Line |
| Bolga 330 kV | 330 | 225.71 | 1.00 | 161 kV Bui-Sunyani Line |
| Bolga 225 kV | 225 | 330.31 | 1.00 | 161 kV Bui-Sunyani Line |
| Kintampo 330 kV | 330 | 333.47 | 1.01 | 330 kV Tamale-Bolga Line |

Table 31 shows the loading on key transmission lines in northern Ghana under contingency conditions. The power flow on each line changes with the contingent element, but only the highest loading on each line and the contingency that causes the highest loading are shown in the table. No overloads are observed under contingency conditions.

**Table 31: Scenario 4 Line Loading Under Contingency Conditions**

| Monitored Line | Rating (MW) | Loading (% of Rating) | Contingent Element |
|---|---|---|---|
| 161 kV Bawku to Zebilla Line | 182 | 2.88 | 161 kV Bui-Sunyani Line |
| 161 kV Bolgatanga to Tumu Line | 364 | 27.16 | 161 kV Sawla-Wa Line |
| 161 kV Kintampo to Bui Line | 364 | 35.91 | 161 kV Bui-Sunyani Line |
| 161 kV Kintampo to Buipe Line | 364 | 45.27 | 330 kV Tamale-Kin Line |
| 161 kV Sunyani to Bui Line | 364 | 33.85 | 330 kV Tamale-Kin Line |
| 161 kV Sunyani to Techiman Line | 244 | 69.42 | 161 kV Bui-Sunyani Line |
| 161 kV Tamale to Yendi Line | 182 | 9.43 | 330 kV Tamale-Bolga Line |
| 161 kV Techiman to Bui Line | 364 | 38.25 | 161 kV Bui-Sunyani Line |
| 161 kV Techiman to Kintampo Line | 364 | 27.88 | 161 kV Bui-Sunyani Line |

| Monitored Line | Rating (MW) | Loading (% of Rating) | Contingent Element |
|---|---|---|---|
| 161 kV Wa to Sawla Line | 182 | 33.68 | 330 kV Tamale-Kin Line |
| 330 kV Tamale to Bolgatanga Line | 1000 | 11.26 | 161 kV Sawla-Wa Line |
| 330 kV Tamale to Kintampo Line | 1000 | 21.59 | 161 kV Kin-Buipe Line |

# V. MODELING RESULTS – TRANSIENT STABILITY ANALYSIS

ICF examined selected contingencies that can affect system stability on a transient basis, including:

- the loss of a major generating unit that provides essential reliability services,
- a three-phase fault on a major transmission line,
- an unplanned outage of a transmission line, and
- the potential loss of the interconnected solar generation plants.

The generator outage contingency tested the system stability after the loss of a generating unit at Akosombo, a major unit that provides flexibility to the system and enables that system to respond quickly to contingences.

The three-phase fault was designed to test the ability of the system to return to a stable operating point following the momentary loss of the 161 kV Sawla to Wa Line, while the line outage contingency assessed the impact of the unplanned outage of the 330 kV Tamale to Kintampo Line.

## V.1. LOSS OF ONE AKOSOMBO GENERATING UNIT

Figure 7 shows system frequency plots for each of the solar PV penetration scenarios for the first few seconds after the loss of a generating unit at Akosombo. The system frequency is at the nominal target of 50 Hz prior to the unit outage, but drops immediately after the loss of the unit.

In the Base Case, Scenario 1, and Scenario 2, the frequency does not exceed the minimum limit of 49.5 Hz allowed under contingency conditions. Further, the oscillations that occur after the loss of the generator are damped after a few seconds. It is therefore likely that the bulk power system will return to a stable state at penetration levels of 10% or lower.

At penetration levels of 20% (Scenario 3) and 30% (Scenario 4), the system frequency falls below 49.5 Hz within 5 to 10 seconds after the loss of the generator. The frequency drops as low as 49.25 Hz in Scenario 3 and 49 Hz in Scenario 4. In addition, unlike the other scenarios, the oscillations that occur after the loss of the generator are sustained. This indicates that at solar PV penetration levels above 10%, there is a risk that the system could violate the stability criteria if there is a loss of one of the hydro units at Akosombo exactly during the peak generation period of the solar plants. Mitigation measures for planning and reliability purposes might be required to increase penetration above 10%.

**Figure 7: Frequency Plot Showing Impact of Loss of an Akosombo Hydroelectric Unit**

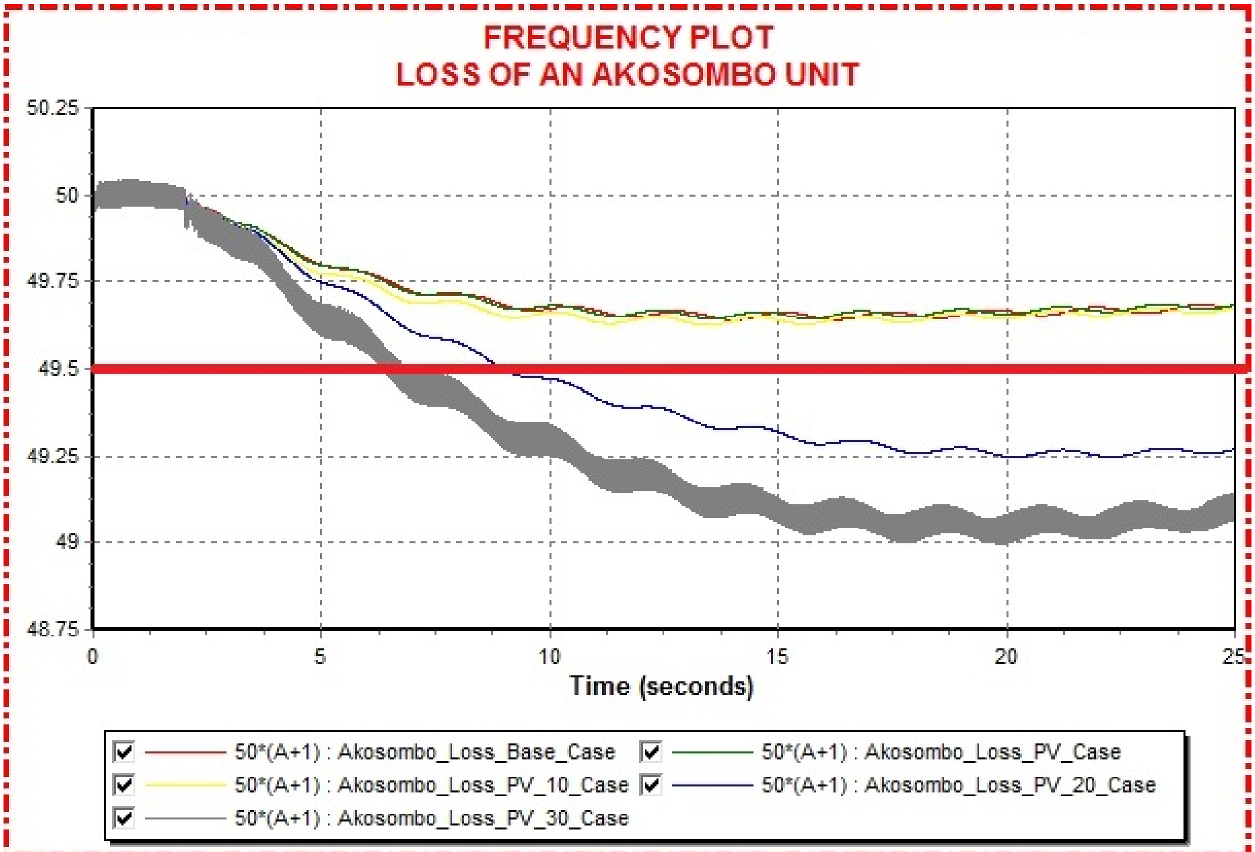
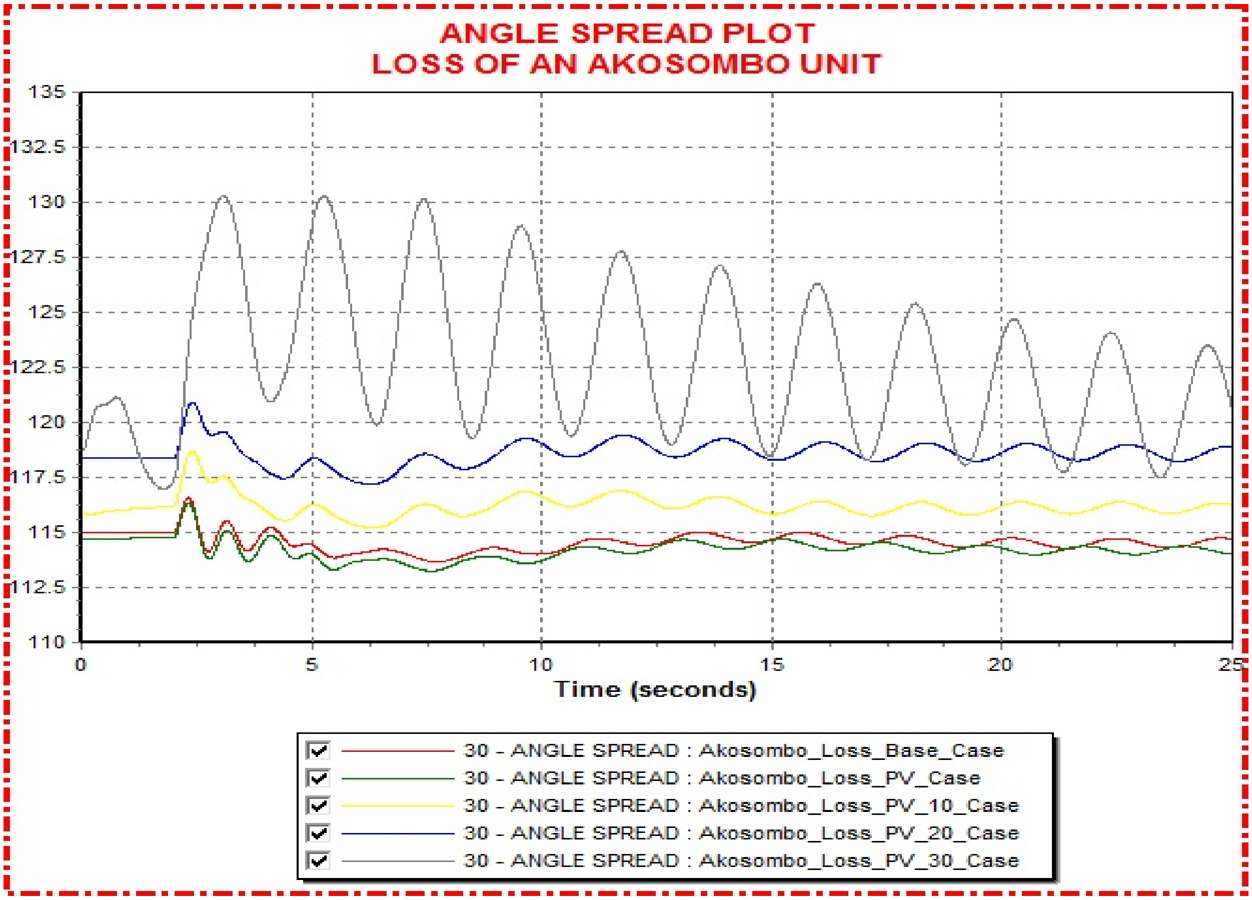



Figure 8 shows a plot of the rotor angle spread for generators in the Ghana bulk power system after a sudden outage of a generation unit at Akosombo. A generator's rotor angle determines it power output. When a disturbance on the bulk power system affects the system frequency, governors on the generator act to adjust the speed of the prime mover, which changes the rotor angle and the power output of the generator in an effort to return system frequency to the required level. Because the system is non-linear, the rotor angle (and power output) might oscillate before returning to a stable state. Under certain conditions there is a risk that the generator might not be able to return to a stable state following the disturbance, which can affect the stability of the bulk power system and even lead to a blackout. System operators keep the rotor angle relatively small, because the narrower the rotor angle, the more stable the system is. An analysis of the generator's rotor angle spread can determine its ability to recover from the oscillations

The rotor angle spread plot shows that in each case, the rotor angle spread increases after the loss of the generating unit, and it starts to oscillate. Similar to the frequency plot, the oscillations are damped after a few seconds in the Base Case, and in Scenario 1 and Scenario 2. In Scenario 3 and Scenario 4, the oscillations are sustained. In addition, the oscillations in Scenario 4 have a much larger amplitude than in Scenario 3 due to the higher solar PV penetration. Therefore, the rotor angle spread analysis also indicates that mitigation measures might be required for a penetration level above 10%.

**Figure 8: Rotor Angle Plot Showing Impact of Loss of an Akosombo Hydroelectric Unit**




## V.2. THREE-PHASE FAULT ON 161 KV SAWLA TO WA LINE

A three-phase faults are the most severe faults on the bulk power system, and they cause the maximum fault currents. Three-phase to ground faults, which in effect connect all three phases of the line to ground, cause severe voltage dips. Automatic devices clear the fault or attempt to clear it within a few cycles. Once the fault is cleared, voltages should return to acceptable levels to maintain reliable operation. In this analysis, ICF simulated a three-phase to ground fault, which was cleared within five cycles.[7]

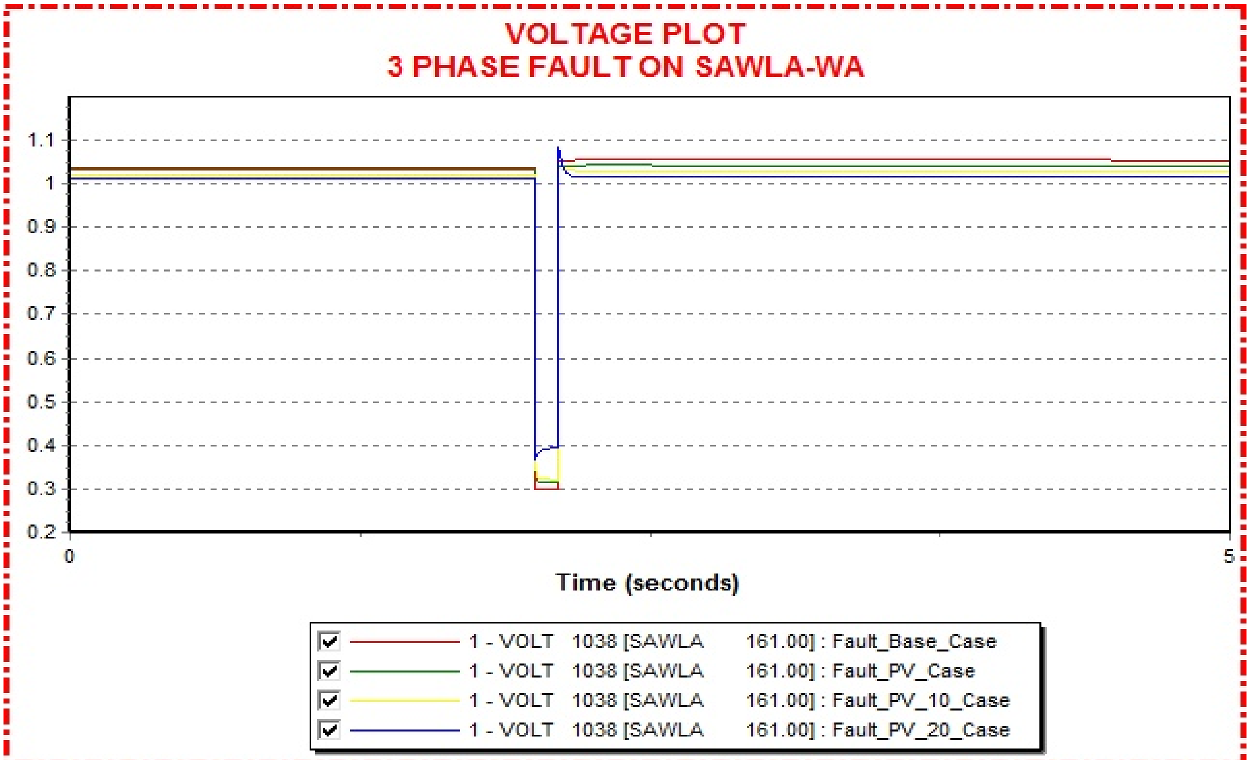
Voltages before, during, and after the fault for each of the scenarios are shown in Figure 9. Voltages are within acceptable limits before the fault, and return to acceptable levels after the fault, although they dip to 0.30 p.u. to 0.37 p.u. during the fault. For penetration levels up to 20% (Scenario 3), the system voltages are able to recover following a three-phase fault on the Wa to

[7] Ghana's bulk power system operates at a frequency of 50 Hz, which means it goes through 50 cycles every second. Five cycles will be one-tenth of a second, or 100 milliseconds.

Sawla Line. Because the inverters of the solar PV plants are configured to provide voltage support, the voltage dip is less severe with increasing penetration of solar PV generation.

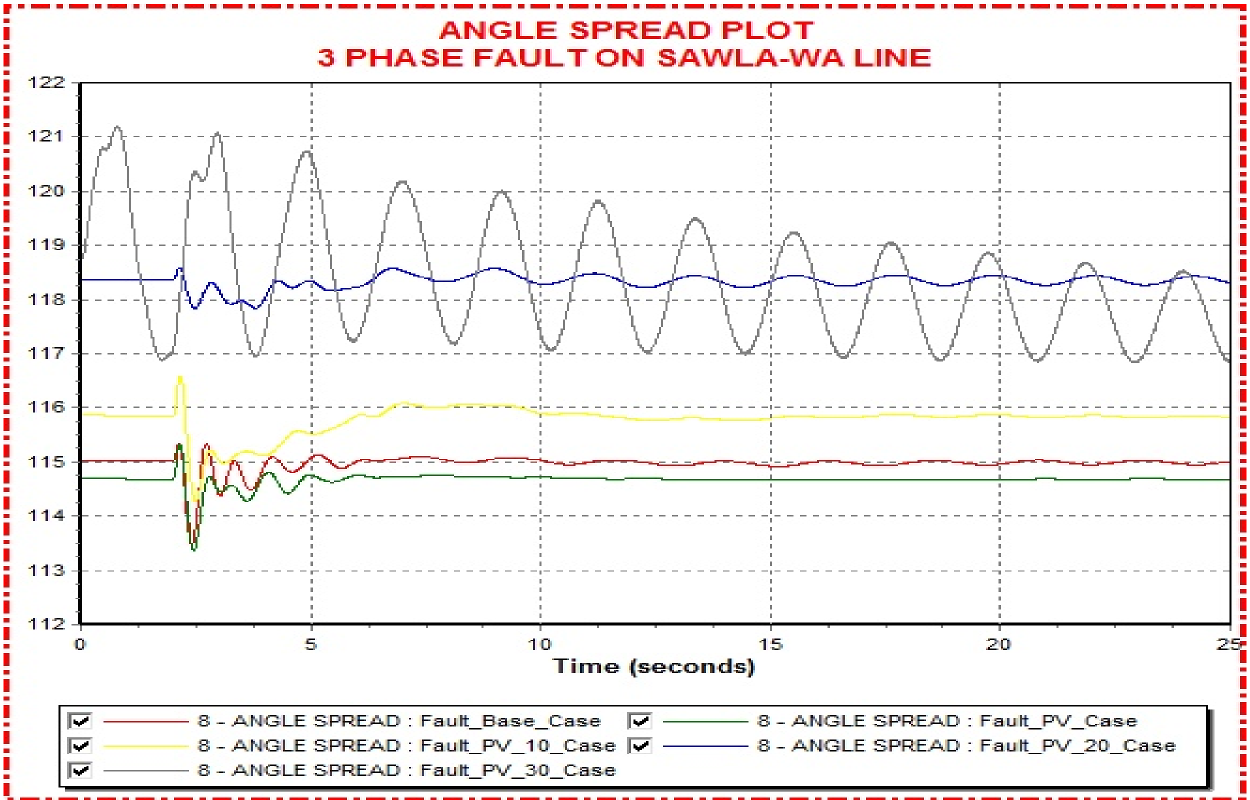
In the Base Case, the voltage dips as low as 0.30 p.u. after the fault. In Scenario 3, with 20% solar PV penetration, the voltage dip is less, falling to 0.37 p.u.

**Figure 9: Voltage Plot Showing Impact of Three-Phase Fault on Sawla to Wa Line**




The results of the rotor angle spread analysis for the three-phase fault on the Sawla to Wa Line shows that mitigation measures might be required for penetration levels above 10%. The rotor angle spread plot is shown in Figure 10. For solar PV penetration levels up to 10%, the rotor angle oscillations are well-damped, and they return to stable conditions after a few seconds. At 20% and higher, the oscillations are sustained. Integrating this level of solar PV generation will require mitigation measures.

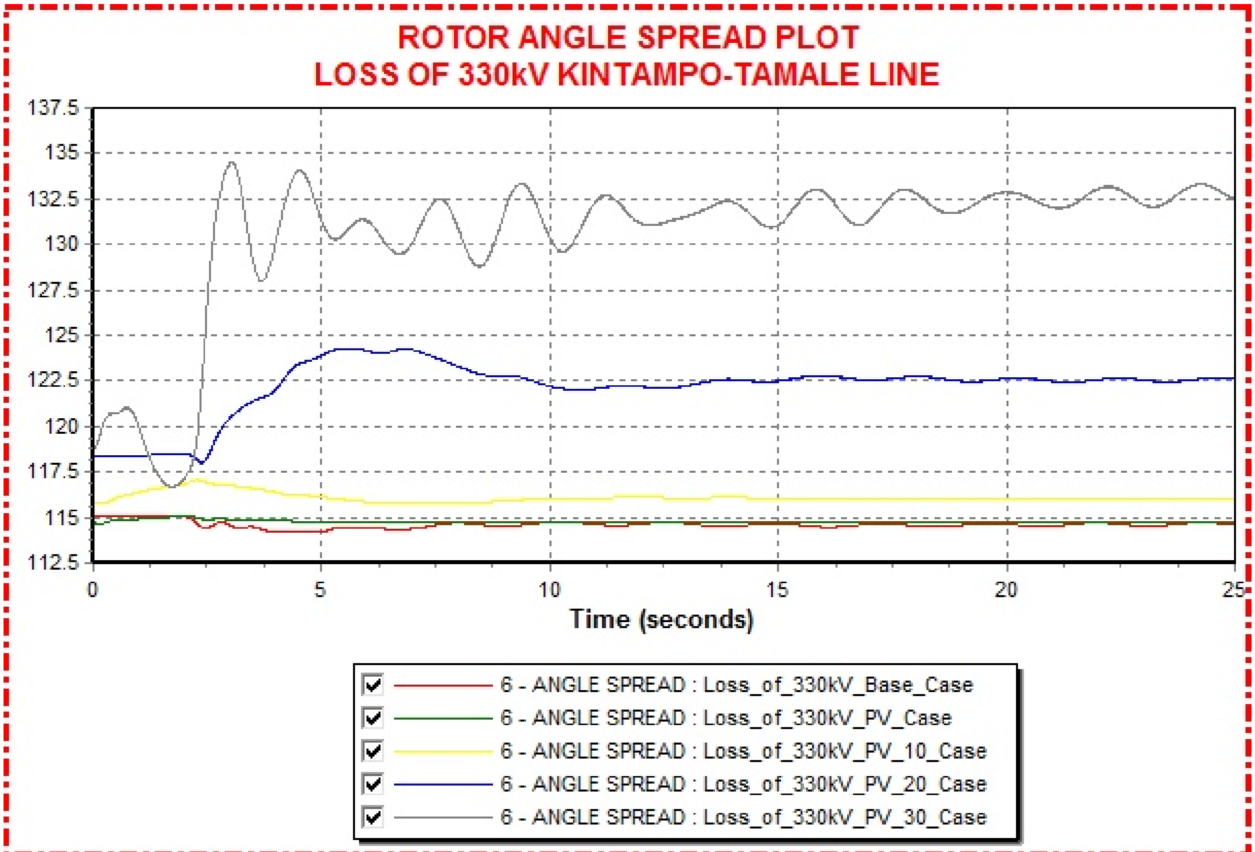
**Figure 10: Rotor Angle Spread Plot Showing Impact of Three-Phase Fault on Sawla to Wa Line**




## V.3. LOSS OF 330 KV TAMALE TO KINTAMPO LINE

The impact of the loss of the 330 kV Tamale to Kintampo transmission line on rotor angle spread differs from the results of the other rotor angle spread analyses. Oscillations are damped for solar PV penetration levels of up to 10% (Scenario 2). The oscillations for 20% penetration (Scenario 3) have a low amplitude compared to 30% (Scenario 4), but they are still sustained.

**Figure 11: Rotor Angle Spread Plot Showing Impact of Loss of Tamale to Kintampo Line**




## V.4. Loss of Solar PV Generation

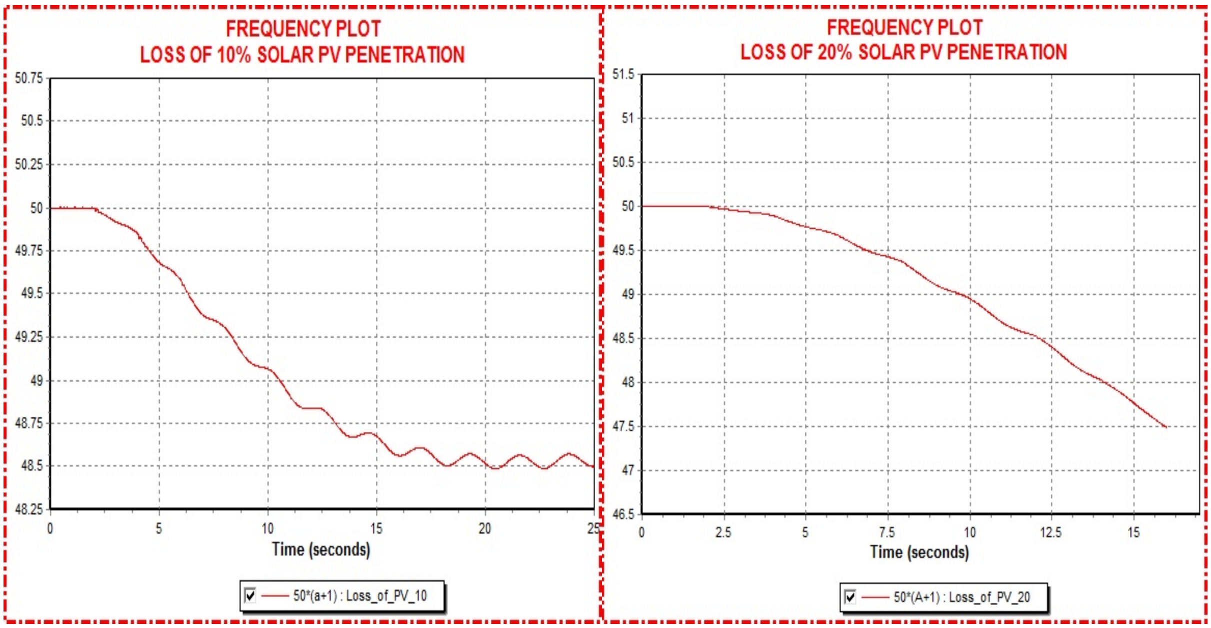
ICF assessed the impact of the loss of all the solar PV plants in the 10% and 20% scenarios. Because the solar PV resources are spread over a large geographic area, it is unlikely that a single event would take the entire set of solar resources completely out of service at the peak time of its generation. Consequently, this is an unrealistic scenario, but it still does assess the ability of the available conventional generation to respond to the loss of the solar PV fleet and maintain system reliability.

ICF assumed the Bui Power Plant to be a peaking plant in this study, and unavailable during the period that the solar PV plants are at their peak dispatch. Therefore, for this analysis, power to replace the loss of the solar PV plants is sourced exclusively from the southeast and southwest generation sources in the Ghana electricity market.

However, the results of this assessment might be instructive in developing a strategy to mitigate potential reliability problems and facilitate the integration of even more solar PV generation. For example, as solar penetration significantly increases in the north of the country, it could be helpful to keep the Bui hydro power ready to operate one unit on standby mode to address ramping needs that might arise due to of the variability of solar generation.

The impact of the loss of the solar PV generation on system frequencies is shown in Figure 12. At 10% penetration, system frequencies fall as low as 48.5%, while at 20% penetration frequencies do not appear to recover. In both cases, the system would likely be plunged into a blackout—however, it should be noted again that the full loss of the entire solar PV system during its peak generation period is an extreme scenario, and has been included just to test the limits of the system.[8]

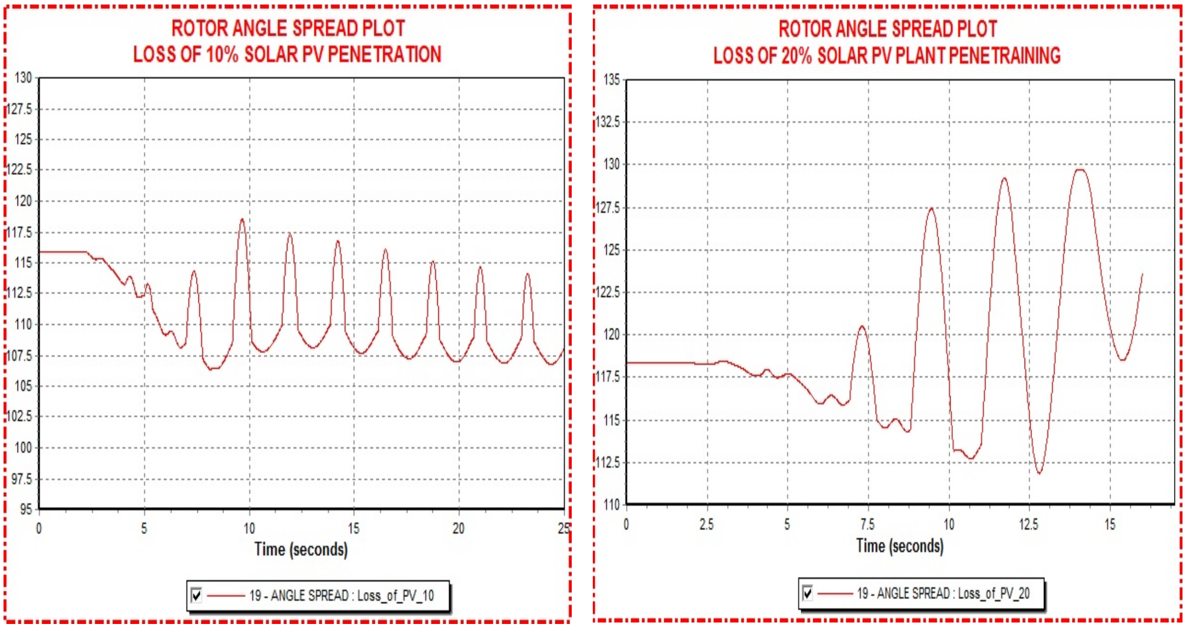
**Figure 12: System Frequency Plot Showing Impact of Loss of Solar PV Generation**




[8] One potential realistic scenario is if a full solar eclipse were to occur between 12 PM and 1 PM on a day with no clouds in the north, and if the umbra happens to cover all of the solar plants at the same time. Even this scenario is unlikely because the umbra is much smaller than size of Northern Ghana.

The impact of the loss of the solar generation on rotor angle spread is shown in Figure 13. In both cases, oscillations are sustained indicating that system stability would be lost under either condition.

**Figure 13: Rotor Angle Spread Plot Showing Impact of Loss of Solar PV Generation**



# VI. KEY FINDINGS AND NEXT STEPS

ICF performed steady state transmission security and transient stability analyses to determine if reliability criteria violations would occur as the level of solar PV penetration increases on the Ghana bulk power system. The analysis showed very few violations under steady state conditions up to a penetration level of 790 MW, or approximately 30% of the total off-peak load of 2,573 MW.

ICF found that at low penetration levels (235 MW or approximately 7% of total off-peak load), some mitigation might be required for small voltage violations. At higher penetration levels, the inverters at the solar PV plants provide sufficient voltage support to resolve any voltage violations. *It is important to configure the solar PV plants to provide the necessary reactive power, as per the Ghana RE Grid Code*.

The transient stability study showed that at penetration levels above 310 MW, or approximately 10% of total off-peak load, there is a risk that unplanned events such as momentary or sustained loss of major transmission lines, or the loss of a unit at Akosombo, could result in severe reliability problems. Akosombo is a flexible, fast-ramping generator that provides essential reliability services. Losing one unit affects the ability of the system to respond to these unplanned events. At penetration levels of 10% or lower, the bulk power system is able to recover from the sudden changes in system conditions caused by the unplanned events and return the system frequency to the nominal value of 50 Hz for stable operating conditions. At higher penetration levels, the perturbations are not damped and could escalate and cause a blackout. Based on this analysis, mitigation measures might be required at penetration levels above 10% of the total generation modeled in the study.

The rapid integration of large scale renewable generation without appropriate mitigation can lead to system stability problems. Therefore, it is recommended that the Ghana should add renewable resources gradually and implement the appropriate mitigation measures as the need arises. Furthermore, there is a need for continuous capacity building of GRIDCo staff (in System Planning and Market Operations) to ensure that they are aware of the best practices, the current solar technologies and their characteristics, and the cost/benefits of solar integration into Ghana's grid and operational issues associated with greater solar penetration.

## VI.1. NEXT STEPS

This study is a high-level assessment designed to provide an indication of the solar PV penetration limits, and the levels at which mitigation might be required. ICF's examined only a few selected conditions. A more comprehensive study is required to determine a more refined measure of the penetration limit, as well as the mitigation measures that would help increase penetration levels.

The next steps might include:

1. Perform a more detailed assessment including examining additional hours of operation and additional contingencies. ICF's study examined a single snapshot of system conditions during the off-peak period and a limited number of contingencies. In line with industry standards, it is important to analyze several different periods of operation to

obtain a more complete view of the impact of renewable penetration over the operating cycle. This could be achieved by carrying out the following:

a. Determine the locations of new solar PV plants in consultation with GRIDCo. This might be based on GRIDCo's knowledge of locations where developers are planning to site solar PV plants in the future, or where GRIDCo determines that solar PV plants would provide support to the system. Analysis such as a hosting capacity study could also help to determine potential locations.
b. Work with GRIDCo to determine additional contingencies that should be examined.
c. Perform a production cost or other appropriate hourly simulation of the operation of the bulk power system and select additional hours of operation for further analysis. The hours selected could be stressed periods such as hours with low system inertia, low ramping capacity online, low net load, or significant congestion,
d. Perform the steady state and transient stability analysis for the selected hours.

2. Perform additional studies to assess other aspects of the impact of renewable penetration. For example, the increase in solar PV could change the performance of the system under contingency conditions, leading to a change in the operating reserve targets. Other studies can assess how much net demand can change over a predefined short interval, which can be used to assess how ramping needs will change as more solar PV is added to the system.

3. Perform additional studies to examine the effects of solar PV penetration in all parts of Ghana, as per the least-regrets and BAU scenarios of the IPSMP.

4. Determine mitigation measures to increase penetration limits.

5. Determine the ability to utilize the Bui Hydro Plant strategically to improve renewable integration. Given its location and fast-ramping capability, the Bui Hydro Plant could facilitate the integration of higher levels of solar PV generation.

6. Update the database on status of solar plant development. GRIDCo should consider developing a generation interconnection queue that will provide non-confidential information on the status of proposed solar and other generation projects in the country. The generation interconnection queue might include information such as capacity and type of plant, proposed interconnection location, expected in service date, and status. This will be a useful tool for regulators, planners, developers, investors, and other stakeholders interested in the Ghana electric sector.

7. Extend the study to cover other aspects of system planning that can support the integration of renewables, including:

a. The feasibility of using solar PV as a non-wires alternative to transmission projects. This can be combined with hosting capacity studies to plan for, and encourage the development of renewable resources.
b. Value of solar studies that can help quantify the potential costs and benefits of solar PV generation. Demonstrating the benefits of solar PV can support

stakeholder decision-making at the local level and encourage private sector participation in resource development.

# H. Renewable Energy Assessment

As part of the IPSMP and the IPM modelling, the IRRP project assessed the potential resource base for renewable energy over the last two years. The report below summarizes the renewable energy assessment conducted thus far, and the assumptions used in the Ghana IPM2018v1.

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# Integrated Resource and Resilience Planning (IRRP) Project

## Renewable Energy Potential in Ghana 2017

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# 1 INTRODUCTION

Ghana has significant renewable energy resource potential particularly in the form of solar, bioenergy (biomass &biogas), wind and in some measure hydropower. These RE resources has the potential to contribute to the achievement of Ghana's Sustainable Energy for All Agenda with the possibility of doubling the share of renewable energy in the national energy mix by 2030.

In view of the potential these renewable energy (RE) resources can have on future power generation in the country the Integrated Resource and Resilience Planning (IRRP) Team, supported by USAID/Ghana, conducted a high level review of existing and potential RE resources. Results from the review will serve as inputs for the Ghana Integrated Planning Model (Gh-IPM). The identification and availability of resource in the country were categorized under model zones in accordance with the Gh-IPM set up. The Ghana IPM has been modelled into four main zones-namely NorthGH, SouthWestGH, SouthEastGH and the AshantiGH. The country was divided into these four zones as a result of an evaluation of transmission constraint and a combination with other factors. Detailed explanation on the zone formation can be found in the main 2018 Integrated Power Sector Master Plan report (Volume 2). Each of these model zone depending on the RE resource present, will require inputs and generation patterns in order to determine capacity of potential builds for the respective zones in the various years of interest.

This report summarizes the findings of the IRRP team's review of the renewable energy resource potential in the country with discussions on the overall resource potential and cost/performance information and assumptions used in the Ghana IPM. The RE technologies considered in the assessment are namely hydropower, wind, solar and bioenergy (biogas and biomass).

# 2 HYDROPOWER

The contribution of hydropower to the Ghanaian power sector has been very significant in the history of the country. Although the share of hydropower generation has been reducing over the years as a result of diversification of sources of power, it still continues to play an integral role in the supply of electricity. It contributed about 5,616 GWh in 2017, representing about 40% of the total electricity consumed that year.

## 2.1 Existing Hydropower in Ghana

The country lies in three main hydro basins which comprises of the South-Western, the Coastal and the Volta Basin Systems with each comprising of other sub-basins.

The Volta basin which is the largest basin system in Ghana comprises of three sub-basins namely the Black Volta, the White Volta and the Oti basins. These basins harbor all three existing hydropower facilities in the country namely- the Akosombo, Kpong and the Bui hydropower plants. The Akosombo dam initially a 912 MW plant, was constructed on the lower reaches of the Volta River, to form one of the largest man-made lakes in the world with a reservoir surface area of about 8502 sq.km. It was later upgraded to a 1020 MW plant after the completion of extensive retrofit in in 2015 capacity. The Kpong HP – is a 160MW a run-of-the-river hydropower station, constructed after the Akosombo further downstream of the Volta River and was primarily constructed to optimize the usage of water for hydropower generation from the Lake. Collectively both the Akosombo and the Kpong have a firm energy of about 4,800 GWh and a long term average capability of 6,100 GWh. The Bui HP, the most recent hydropower plant developed in the country, was commissioned in 2013 and is located on the Black Volta River approximately 150km upstream of the Volta Lake. It has a net average long-term energy generation output of about 969 GWh. Together these three hydropower plant represents about 40% of the country's installed capacity in 2017.

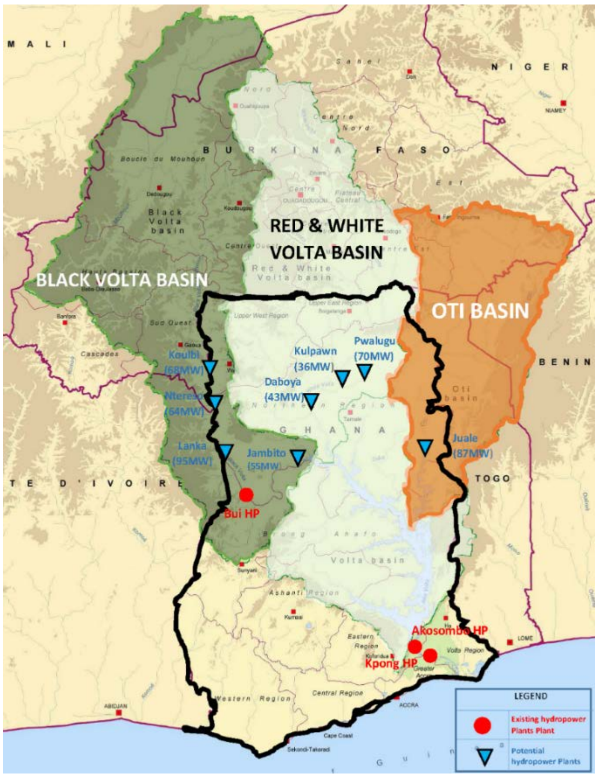



*Figure 1 Hydropower Potential in the Volta Basin*

*Source: Potential site and Basin Illustration - IRRP Project; Map (Glowa, 2017)*

## 2.2 Small/ Medium Scale Hydropower Potential

Over sixteen (16) small to medium scale potential hydropower sites have been identified in the country since the early 1920s, with most of these sites located in the Volta and Southwestern river basins. The actual techno-economic potential of these site is very uncertain due to the fact that existing studies on these site are very outdated.

### *2.2.1 Potential Sites in Volta Basin*

The Volta Basin being the largest basin has the most number of potential hydropower sites as shown in Figure 1. It primarily consists of the three sub basins n amely the of the White, the Red and the Black Volta. However, all seven potential hydropower site identified are on the Black and White Volta.

The potential hydropower sites found on the White Volta are the Pwalugu, Kulpawn and the Daboya with a total potential of about 149 MW. These projects are one of the very few which have had the benefit of a relatively more recent study especially the Pwalugu hydropower project. The capacity of multipurpose Pwalugu which was identified to have a potential capacity of about 70 MW may even be reviewed downwards after the completion of the ongoing study.

There are also a couple of potential hydropower sites found on the Black Volta basin namely the Koulbi, Ntereso, Lanka and the Jambito. The viability of these projects however are very uncertain due to the fact that these site which are in close proximity to the Bui HPP were identified prior to the construction of plant and their viability- especially Lanka and Jambito – is likely to have been affected. Further detailed studies must be done to confirm this.

The proposed multipurpose Juale project which is the only one located on the Oti river, will be a transboundary project, flooding some parts of Togo which shares the basin with Ghana and Benin. The project is envisaged to greatly impact rice production in the surrounding valleys due its irrigation component, similar to the Pwalugu project. However, it is relatively an expensive project given its associated environment and social cost and might require further studies to optimize its viability.

*Table 1: Characteristics Of Potential Small- Medium Hydropower Projects In Ghana*

| Name | River Basin | Installed capacity [MW] | Ave. Energy Gen [GWh/an] | Year of Study |
|---|---|---|---|---|
| Pwalugu | White Volta | 70 | 209 | 2014* |
| Daboya | White Volta | 43 | 194 | 1992 |
| Kulpawn | White Volta | 36 | 166 | 1992 |
| Koulbi | Black Volta | 68 | 392 | 1984 |
| Ntereso | Black Volta | 64 | 257 | 1984 |
| Jambito | Black Volta | 55 | 180 | 1984 |
| Lanka | Black Volta | 95 | 319 | 1984 |
| Juale | Oti | 87 | 405 | 1992 |
| Jomoro | Tano | 20 | 85 | 1984 |
| Asuaso | Tano | 25 | 129 | 1984 |
| Sodukrom | Tano | 17 | 67 | 1984 |
| Kojokrom | Pra | 30 | 136 | 1984 |
| Tanoso | Tano | 56 | 258 | 1984 |
| Abatumesu | Pra | 50 | 233 | 1984 |
| Hemang | Pra | 60 | 216 | 2012 |
| Awiasam | Pra | 50 | 205 | 1984 |

**Study still ongoing*

### 2.2.2 The Southwestern Basins.

The southwestern basin system falls in a relatively humid climatic zone which is greatly influenced by the south-west monsoons during the rainy seasons. The major rivers in the basin are the Bia, Tano, Ankobra and the Pra. Of these major rivers, only the Tano and the Pra has identified hydropower sites- shown in Figure 2.

*Figure 2 Hydropower Potential in the South-western Basin*


*Source: Map (Glowa, 2017) Illustration IRRP Project*

The total hydropower capacity identified on the Tano river is about 118 MW with an estimated aggregated annual energy generation of about 539 GWh.

The Pra basin is the largest basin in the south western basin systems traversing through four administrative regions in Ghana namely the Ashanti, eastern, central and the western regions. The total hydropower potential in this basin is estimated to be about 190 MW with an annual generation of about 790 GWh. The potential sites for hydropower development identified thus far are Awisam, Hemang, Abatumesu and Kojokrom as shown in Figure 2.

However as earlier mentioned, these technical parameters are from very old studies (Acres 1984) with only Hemang undoing a more recent study in 2012. The location of these sites are in a relatively humid climatic zone with the vegetation in the basin, primarily rain forest and the semi-deciduous forest. It is therefore likely that many hectares of fertile lands or farmland will be inundated if the original estimate of capacities are to be realized, which will render the project economically unviable. Therefore these site are in need of more recent studies, although their stated capacities and generation outputs are likely to reduce due to several factors some of which are socio-economic activities in the areas of interest and possible hydrological changes.

## 2.3 Hydropower information for GH IPM

All three exiting hydropower plants- Akosombo, Kpong and Bui - have been included in the Ghana IPM as existing units. Details of these units and projected capacity factors can be found in the IPSMP Volume 2.

Due to existence of small to medium potential hydropower sites in the country, the Ghana Integrated Planning Model needed to include hydropower as an option in the generation potential available for the country in the model. The location of these hydropower sites are found in only two of the Gh IPM zones, namely the NorthGH and the South WestGH zones. However only three possible hydropower site were included in the model namely the Pwalugu, Hemang and Juale. These are the sites which have recently benefited from updated studies and relatively more accurate technical parameters. Juale is also seen as a more viable alternative to Kulpawn and Daboya.

Since IPM uses renewable generation profiles to specify the daily generation pattern for a hydropower capacity expansion a capacity factor profile which is an average for all three hydropower site were used in the model. This is basically the capacity factors multiplied by 1000 as shown in the table below. Updated version the model can include any new hydropower site with updated information on the capacity factors and a profile for each of the potential sites.

*Table 2: Generation Pattern for Hydro Units in Gh IPM*

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Generation (kW/MW) | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |

Capital cost (includes interest during construction) estimates used in the model were derived from analysis of information obtained for cost of most recently developed hydropower plant in the country and the proposed cost estimated for some of the recent feasibility study of similar hydropower projects in the country. Three cost options and capacities are available in the model for the model zones of interest. Details of cost assumptions can be found in the IPSMP Report. The table below summarizes the cost assumption used for hydropower plants in the *GH-IPM 2018v1*.

*Table 3: Hydropower Cost Estimates used in the Ghana IPM*

| Zone | Capital Cost (2006$/kW) | Fixed O&M (2016$/kW-yr) | Variable O&M (2016$/kW-yr) |
|---|---|---|---|
| North GH | 6000 | 45 | 3 |
| South West GH | 5000 | 45 | 3 |
| North GH | 4000 | 45 | 3 |

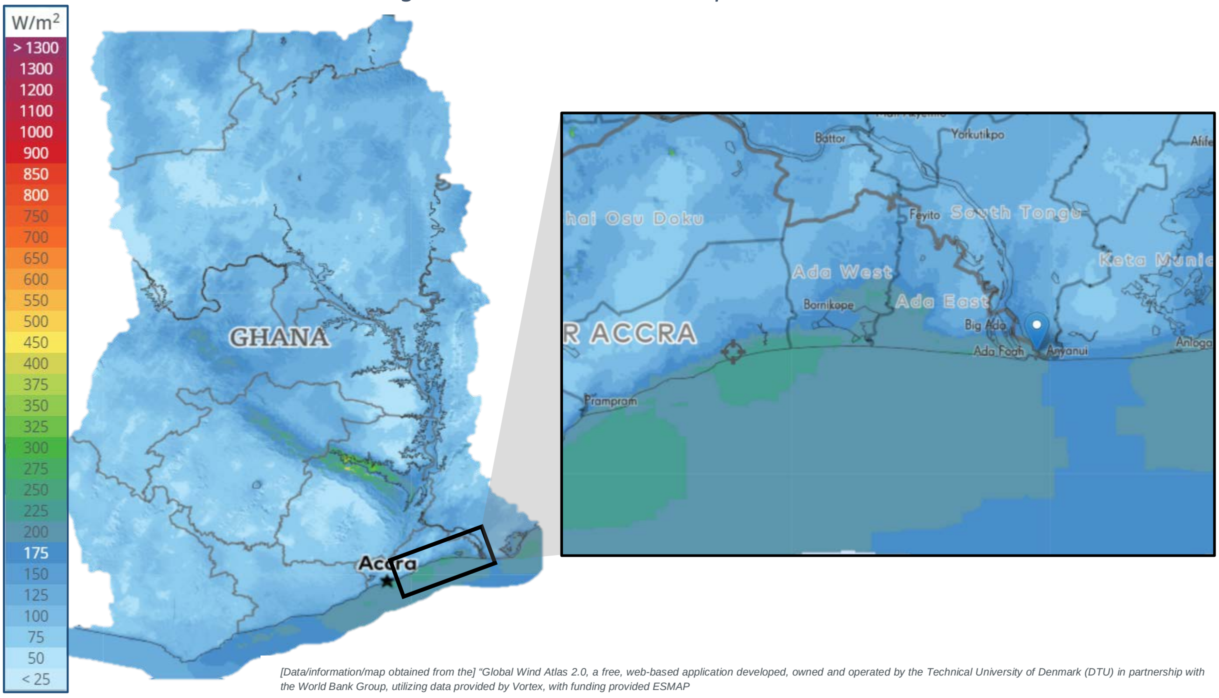
# 3 WIND POWER POTENTIAL IN GHANA

## 3.1 Wind Resource

Wind is one of the key renewable energy resources Ghana is looking to tap into as a source for power generation. However, there are presently no utility scale wind farms in the country although there have been keen interests shown by some investors.

Extensive resource assessment conducted to estimate the potential wind resource in the country has mostly been led by the Energy Commission in partnership with other international agencies. However, wind resource measurement in the country are being undertaken by several interested parties including the Energy Commission, the Ghana MeteorSNological

*Figure 3: Wind Resource Map- Ghana*




*[Data/information/map obtained from the] "Global Wind Atlas 2.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilizing data provided by Vortex, with funding provided ESMAP*

Services Department, VRA and other interested private investors. The concentration has however been along the south eastern coastlines. This is because the location has relatively good wind resource on a fairly flat terrain with proximity to transmission infrastructure. This is in contrast to other locations such as the Kwahu South area and along the Ghana-Togo border which has also been identified to have a good wind resource. However, this terrain is very mountainous and will require lots of investment in transmission infrastructure if the wind power generation is to be connected to the National Interconnection Transmission System. The estimated total technical wind potential in Ghana though is in excess of 5000MW (IRENA, 2015).

Recent resource assessment by the Energy Commission indicates relatively higher average monthly wind speeds along the south eastern coastline as indicated in the table below, with Anloga measuring the highest of around 6m/s at hub height of 60m-Table 4.

*Table 4 Monthly Average Wind Speed At Some Measurement Sites in Ghana*

| | Site Name | Location | Monthly Average Wind Speed @ 60m (m/s) |
|---|---|---|---|
| 1 | Sege/Ningo | Greater Accra Region | 5.46 |
| 2 | Atiteti/Dzita | Volta Region | 5.98 |
| 3 | Anloga | Volta Region | 6.01 |
| 4 | Mankoadze | Central Region | 5.05 |
| 5 | Denu | Volta Region | 5.17 |
| 6 | Gomoa Fete | Central Region | 4.53 |
| 7 | Avata | Volta Region | 5.01 |
| 8 | Ekumfi Edumafa | Central Region | 4.67 |

Source: Ghana Energy Commission (2016)

## 3.2 Wind Information for the Ghana IPM

Given the availability of wind resource in the country, it was necessary to include wind resource as a generation option in the GH IPM Model. The allocation of the resource however, was limited to the South East zone, given that fact that it was the only zone where extensive wind resource data was being collected by the Energy Commission. This region has also been the interest of many potential wind developers including VRA and is attractive because of the availability of ground measured data and the proximity to transmission and transport infrastructure which will facilitate the development of wind farms.

Ground measured wind speed data were analyzed and an hourly generation pattern in kW per MW was estimated from the wind speed data for each month of the year which was then used for the wind generation profiles in the Ghana IPM.

Cost estimates were arrived at from a market analysis of recent and forecasted cost and performance of new wind farms around the world. However due to the fact that wind power plants are expected to benefit from cost and performance improvements resulting from technological advancement over time, the wind plants in the model have been modelled to see a declining cost over time. The table below summarizes the cost parameters included in the model.

*Table 5: Wind Cost estimates for GH IPM*

| Year | Capital Cost (USD/kW) | Fixed O&M ($/kW-yr) |
|---|---|---|
| 2020 | 1547 | 46.7 |
| 2026 | 1460 | 46.7 |
| 2035 | 1344 | 46.7 |

# 4 SOLAR RESOURCE POTENTIAL IN GHANA

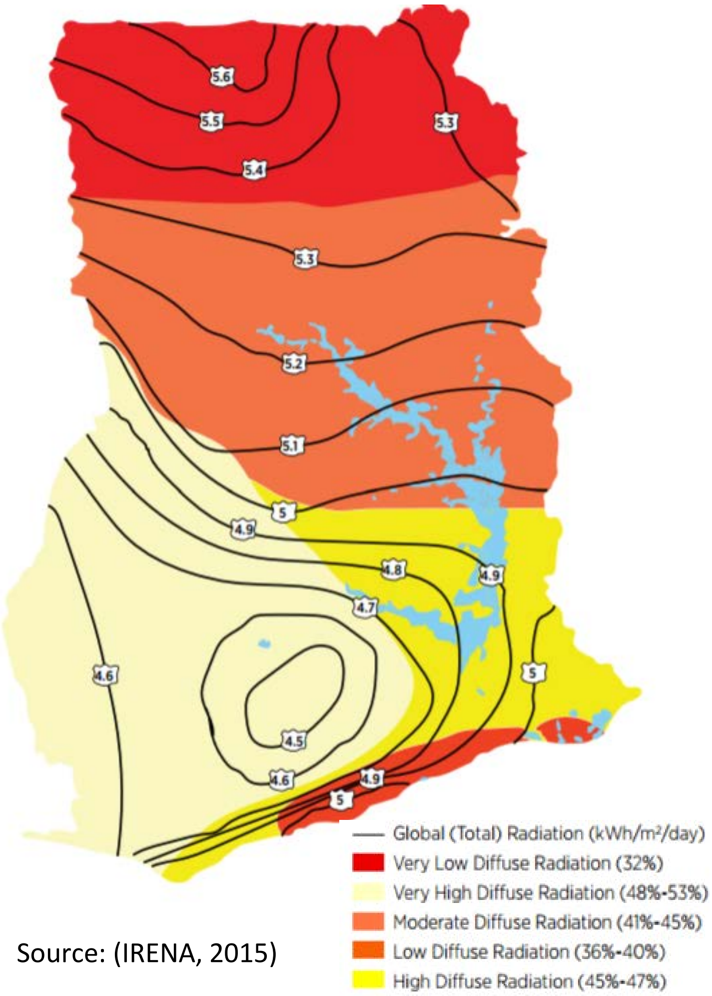
## 4.1 Solar Resource

Solar resource is among the most abundant renewable energy resource in Ghana and has the potential to be a key energy source for power generation in the country. It is estimated that the monthly average irradiance in the country ranges between 4.4 - 5.6kWh/m$^2$/day (IRENA, 2015) with annual sunshine duration between 1500 -3000hours. These are generally ideal conditions for solar to be harnessed for power generation. Generally, a major component of measured global irradiance in the country is diffused. Although the northern part of the country records relatively higher irradiance levels compared to the southern area, the maximum recorded irradiance is still not ideal (high enough) to make Concentrating Solar Plants (CSP) economic/viable. The relatively abundant diffuse radiation makes the Solar Photovoltaic (PV) technology a more sustainable option for solar power generation. Refer to Figure 4 for the solar radiation map of Ghana.

## 4.2 Existing Solar Plants

There are presently two solar PV plants in the country with a total capacity of 22.5MW. A 2.5MWp solar plant owned by the Ghanaian parastatal, Volta River Authority, is located in Navrongo in the Kassena-Nankana District in the Upper East Region of Ghana. The other plant, the BXC 20MWp solar plant is located in Winneba in the central region of the country and owned by BXC Ghana Limited, a Ghanaian registered limited liability company which is a subsidiary of Xiaocheng Electronic Technology Stock Co. Ltd in China. Both plants are all connected to the medium voltage distribution system, and have availability factors of about 18% and 15% respectively and a total annual energy generation of about 36GWh.

*Figure 4: Global Solar Irradiation in Ghana*




Source: (IRENA, 2015)

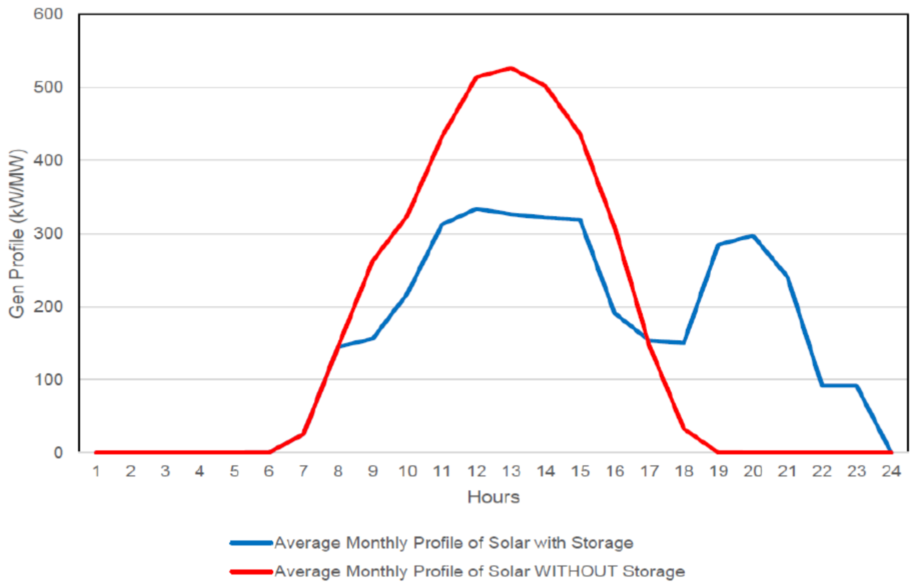
## 4.3 Solar Information for the Ghana IPM

The two existing solar plants have been modelled in the Ghana IPM, with their respective installed capacities and availability included to reflect their techno-economic features.

Due to the fact that solar resource is ubiquitous in all areas in Ghana, this resource is available as a potential resource in all four zones in the Ghana IPM i.e. the North–GH, South West–GH, South East-GH and Ashanti GH. Solar PV with storage option was also included as a generation option in the model.

The daily generation pattern for existing plants was analyzed and used for the solar generation profiles in the Ghana IPM due to the lack of specific data for the respective model zones. The generation pattern for the Solar PV with storage was also included in the model with storage only being available for about six hours in the night and hence contributes only about 30% to reserve margin. Figure 5 shows a typical hourly solar profile in the model.

*Figure 5: Typical Solar Profile in IPM*




Just like the wind plants, Solar PV is foreseen to also benefit from cost and performance improvements resulting from technological advancement over time. Cost parameters therefore used in the model were derived from analysis of the cost of recent solar projects in the region and reduction factors (from market analysis) to reflect the declining cost over time. The cost assumptions for the model are detailed in the table below.

*Table 6: Solar Economic Assumptions for the GH IPM*

| Plant Name | Capital Cost (2016 USD/kWh) | Fixed O&M (2016 USD/kW-yr) |
|---|---|---|
| **Solar 2018** | 1243 | 24.8 |
| **Solar 2020** | 1,020 | 24.8 |
| **Solar 2026** | 895 | 24.8 |

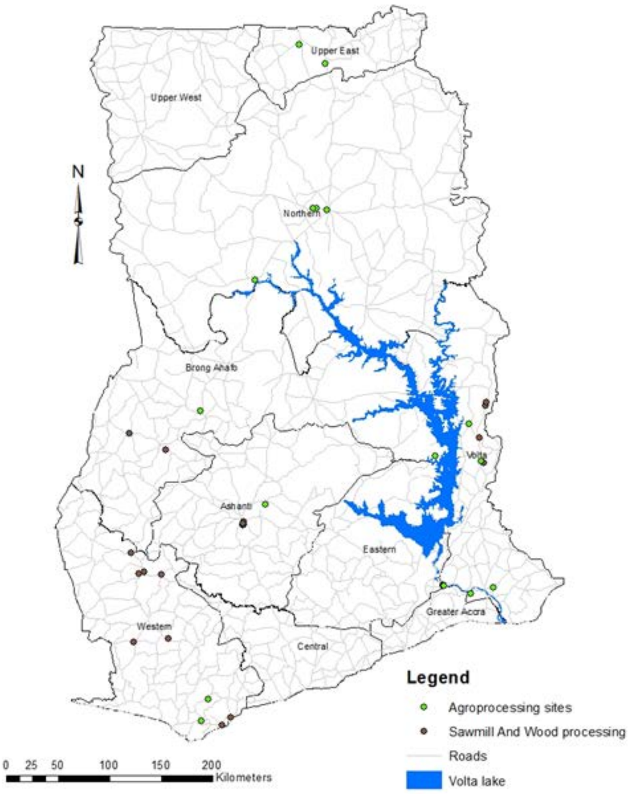
# 5 BIOENERGY RESOURCE POTENTIAL

## 5.1 Biofuel resource

There is a huge potential for Ghana to use biofuels for electricity generation due to the widely available feedstock materials from residues resulting from the various stages of agricultural and forestry activities. Potential sources include crop harvesting residues, wood logging residues, wood processing residues, agro processing residues, residue from farm animals and biodegradable waste which includes organic components of municipal wastes and other commercial and domestic activities. The potential energy alone from crop residue has been estimated to be about 75TJ (RVO.nl, 2014) whilst logging residues generated annually has also been estimated to be about 1.0-1.4 million cubic meters (Government of Ghana, 2012). shows the distribution of some agro processing and saw mill sites in the various regions in Ghana. It shows potential areas of interest for setting up plants to utilise these resources. However, a more comprehensive studies will result in a better resource profiling and characterization of this resource for power generation.

The management of municipal solid waste (MSW) in Ghana has been a continuous challenge facing municipal assemblies and local authorities in the country for some time now. The successful utilization of MSW to generate electricity will help address the waste challenge in the country and also serve as a sustainable power generation option. The two major capital cities in the country, Kumasi and Accra, including their respective suburbs and surrounding areas have been estimated to produce a total of about 4,100 tonnes daily (IRENA, 2015). It has also been estimated that 60% of waste generated in Accra is organic in nature (RVO.nl, 2016) which makes it ideal to use advanced gasification processes to produce syngas or biogas for electricity generation.

Figure 6: Agroprocesing and Sawmill Sites Resource Map




Source: Energy Commission, 2016

## 5.2 Existing Bioenergy Plants

Presently there are no bioenergy generating plants directly connected to the national grid. However, there are some agro processing companies in the country with small onsite generations plants which utilizes their residues as feedstock to generate electricity for local consumption. A couple of them have been listed in Table 8 below.

Another smaller biomass plant is managed by the Safi Sana Ghana Ltd, which operates the Safi Sana factory located in Ashaiman in the Greater Accra region. The plant has the capacity to daily process about 25 tons of wastes for electricity generation and fertilizer production. It presently has an installed capacity of 100 kW with the potential to expand. The plant is connected to the distribution system.

*Table 7: Biomass-fired co-generation palnts in Ghana*

| Plant Location | Installed Capacity, kW | Average Annual Production, GWh |
|---|---|---|
| Ghana Oil Development Company, Kwae | 2,500 | 6.8 |
| Juaben Oil Mill, Juaben | 424 | 1.5 |
| Benso Oil Mill, Benso | 500 | 1.9 |
| Twifo Oil Palm | 610 | 2.1 |

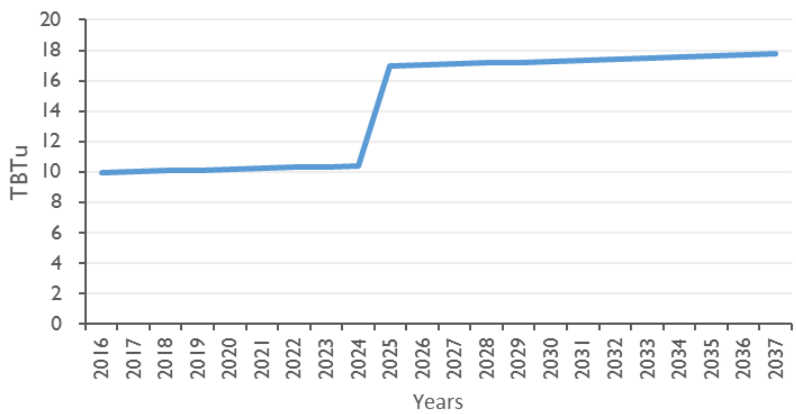
## 5.3 Bioenergy Information for the Ghana IPM

Given the extensive bio energy resources available in all regions of the country for electricity generation, both the biogas and biomass generation options were made available in all four model zones in the Ghana IPM. The cost estimates and assumptions for these technologies have been summarized in the Table 9 below. Biomass is offered as a fuel for potential (new) biomass direct fired boilers and biogas plants (waste to energy), and they contribute 100% to the reserve margin. Biomass fuel is needed in the model for power generation were made from a high level estimate of biomass resources from crop residue, wood etc.

*Table 8: Cost Inputs for Biogas and Biomass technologies in the Ghana IPM*

| Technology | Capital Cost (US$/kW) | Fixed O&M (US$/kW-yr) | VOM (US¢/kWh-yr) | Cost of Energy (US¢/kWh) |
|---|---|---|---|---|
| Biogas | 4200 | 410 | 5.5 | 17.55 |
| Biomass | 3700 | 110.3 | 4.5 | 16.4 |

*Figure 7: Biomass Fuel Constraint*



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# I. MINIGRID WORKSHOP REPORT

In March 2017, the IRRP project held a workshop on the challenges and opportunities in developing minigrids in Ghana, as one of the options to increase electricity access to remote areas and island communities in Ghana. The workshop was held in coordination with African Development Bank, the World Bank, and USTDA.

The agenda and proceedings of the workshop are provided below.

# Actualizing Minigrid Policy and Advancing Universal Energy Access in Ghana: *An Action Learning Event*

## Background and Context

A number of East African countries, like Kenya and Tanzania for example, are actively working to support the application of minigrids and encourage private sector participation as a means to sustainably supply energy to their rural populations.

Ghana is also supporting minigrids, and solar minigrids in particular, to electrify areas that may not be reached by the national grid in the near future. Hence, minigrids present an important opportunity to bring energy and economic opportunities to communities as solar technology costs continue to decline and new business models emerge.

Although Ghana has one of the highest electrification rates in Sub-Saharan Africa, there are still roughly two million people living in rural and/or isolated areas where the grid is unlikely to reach them within the next ten years. In Ghana's rural areas, roughly 59% of communities do not have access to electricity, including a number of communities living on islands in Lake Volta and in isolated lakeside locations. There are currently five minigrid pilot projects in Ghana and a handful of commercial minigrids. However, the successful proliferation of minigrids across rural Ghana will require the adoption of specific policies, technical standards and regulations.

Numerous development partners, international initiatives, and private sector companies are working to ensure universal energy access through a variety of means including minigrids. Minigrids have long served as a means of electrifying rural areas around the globe and are recently being applied to the energy challenges of Sub-Saharan Africa.

The purpose of this Action Learning Event, "**Actualizing Minigrid Policy and Advancing Universal Energy Access in Ghana**" workshop, is to explore the policy and technical issues related to minigrids and facilitate a discussion that will enhance the successful implementation of policies that will encourage widespread minigrid build-out and ultimately universal energy access in Ghana.

List of Supporting Partners include:

**Actualizing Minigrid Policy and Advancing Universal Energy Access in Ghana**

**Agenda**

**March 23-24, 2017**

**Alisa Hotel, North Ridge, Accra**

| Day 1 – Thursday March 23 | |
|---|---|
| **8:30 – 9:00** | **Arrival and Registration** |
| **9:00 – 9:05** | **Introduction and Welcome** – Dr. Ananth Chikkatur, Chief of Party, IRRP Project |
| **9:05 – 9:25** | **Opening Remarks by Development Partners**<br>Andrew Karas, USAID Ghana Mission Director<br>Kennedy Mbekeani – Country Manager – African Development Bank Ghana Office |
| **9:25 – 9:40** | **Keynote Address by Minister of Energy** |
| **9:40 – 9:50** | **Group Photo** |
| **9:50 – 10:30** | **Context: State of Minigrid Policy in Ghana**<br>• **Current Minigrid Policy and Regulations:** Role of Minigrids in Electrifying Ghana: Locations, Limitations, Expectations, Financing Timeframes<br>o Wisdom Ahiataku-Togobo, Director, Renewable and Alternate Energy, MoP<br>o EC Kwabena Otu-Danquah, Director, Renewable Energy, Energy Commission<br>• **State of Demonstration Projects in Ghana**<br>o Henry Vanderpuye, GEDAP Manager<br>o Seth Mahu, Deputy Director, Renewable and Alternate Energy, MoP |
| **10:30 – 10:40** | Coffee Break |
| **10:40 – 11:30** | **Private Sector Perspectives and Role in Ghana's Minigrid Scale-up**<br>• Blackstar Energy<br>• TecnoAmbiental (TTA)<br>• KITE |
| **11:30 – 1:30** | **Regulatory and Commercial Issues: Lessons from Minigrid Successes in Other Countries**<br>*Anastas Mbawala (World Bank); Pepin Tchouate (Power Africa), Ewan Bloomfield (Power Africa), Emmanuel Biririza (African Development Bank)*<br>o Pricing Policies: Tariff Rates and Subsidy Mechanisms<br>o Engaging the Private sector<br>o Billing and Revenue Collection: Customer Satisfaction and Expectations, Mobile Financing<br>o Technical Standards for Minigrid Construction, Operations, Maintenance<br>o Sustainability: Asset Management (what happens when the grids arrives?)<br>o Q&A |
| **1:30 – 1:35** | **Closing Remarks**<br>Ing. Barfour, GEDAP Project Coordinator<br>Waqar Haider, Senior Adviser, USAID/Ghana |
| **1:35 – 2:30** | **Lunch** |
| **2:30** | **End of Day 1** |

** A smaller group will gather on Day 2 to focus on specific minigrid-related recommendations for enhancing the implementation of policies to support minigrid expansion in Ghana. These recommendations can form the basis for further discussions between the GoG and development partners for supporting minigrid expansion.

The group will consist of government officials, experts and development partners (e.g. ~5-6 government officials, 2-3 external experts, and 4-5 Development Partners (e.g. ESMAP, USAID, DFID, USTDA)

| **Day 2 – Friday March 24 – Closed Door Working Session** | |
|---|---|
| **8:30 – 9:00** | **Arrival and Registration** |
| **9:00 – 9:05** | **Introduction and Welcome** – Sunita Dubey, ESMAP World Bank |
| **9:00 – 9:15** | **Overview of Agenda & Goals**<br>Thomas Akabzaa, Chief Director, MOP |
| | **Session 1: Regulatory Framework for Off-Grid Development** (permitting, licensing, interconnecting to grid, asset management) |
| **9:15 – 9:25** | **1a. Recommendations for Discussions, based on Day 1** |
| **9:25 – 10:15** | **1b. Discussion & Development of Group Recommendation** |
| **10:15 – 10:25** | **1c. Finalized Recommendations** |
| **10:25 – 10:35** | **Coffee Break** |
| | **Session 2: Commercial and Tariff Framework for Off-Grid Development** (private sector role, tariffs and cross-subsidies, asset management) |
| **10:35 – 10:45** | **2a. Recommendations for Discussion, based on Day 1** |
| **10:45 – 11:40** | **2b. Discussion & Development of Group Recommendation** |
| **11:40 – 11:50** | **2c. Finalized Recommendations** |
| | **Session 3: Technical Framework and Standards for Off-Grid Development** |
| **11:50 – 12:00** | **3a. Recommendations for Discussions, based on Day 1** |
| **12:00 – 12:40** | **3b. Discussion & Development of Group Recommendation** |
| **12:40 – 12:50** | **3c. Finalized Recommendations** |
| **12:50 – 1:00** | **Closing Remarks**<br>Wisdom Ahiataku-Togobo, Director, Renewable and Alternate Energy, MoP |
| **1:00** | **End of Working Session and Lunch** |

# Report of Mini-grid Workshop

**TOPIC: Actualizing Mini-grid Policy and Advancing Universal Energy Access in Ghana: *An Action Learning Event***

***Date: March 24, 2017***

# Contents

# 1 Background

One of the key measures and strategies adopted by the Government of Ghana towards attainment of universal access (90% population coverage) to electricity is the deployment of mini-grids to remote areas and island communities which are not connected to the national electricity grid. The IRRP project with recourse to one the focal areas of the work plan - providing technical support towards the actualization of the mini-grid policy of Ghana organized a two day workshop in collaboration with the Ministry of Energy, the Energy Commission, the World Bank, the African Development Bank, USAID, and other key stakeholders. The objective of the workshop was to explore the policy and technical issues related to mini-grids and facilitate a discussion that would enhance the successful implementation of policies that encourage widespread mini-grid build-out, and ultimately universal electricity access in Ghana. This approach was to assemble experts and professionals from the key stakeholder institutions/entities and draw from the experiences of countries with comparable situations to Ghana, and come out with appropriate recommendations for consideration of the Ministry of Energy.

The workshop was held on March 23 – 24, 2017. Day One of the workshop assembled a wider audience and focussed on presentations on topical issues related to mini-grids. Day Two was used to discuss extensively, the issues that resulted from discussions on Day One and came up with recommendations which would be presented to the Minister of Energy to enhance the sustainable implementation of the mini-grid policy in Ghana. A smaller group of people assembled for Day Two.

## 1.1 Opening Comments

The activities for Day one commenced at 9:15 am. Dr. Ananth Chikkatur, the Chief of Party (COP) of the IRRP project having called the meeting to order, welcomed all to the workshop and expressed his gratitude to everyone for making time to attend the workshop. He acknowledged the presence of the key institutions and individuals before inviting the USAID Mission Director, Andy Karas to give his opening remarks.

***Opening remarks by Andy Karas:***

The Mission Director began by thanking the IRRP team for the great job done thus far, and also for facilitating the mini-grid workshop. He acknowledged the presence of key personalities particularly the designee of the Minister of Energy, Ing. Andrew Barfour and the Country Manager AfDB, Kennedy Mbekeani. He commended the efforts of the Ministry of Energy (MoEn) in increasing the access to electricity in the country, and requested the Minister's designee to convey his congratulatory message to the Minister on his appointment to the position. The Mission Director also hailed Ghana's position as a leader in electricity access on the African continent.

On the issue of ownership of projects and initiatives by the host country, he commended the IRRP team for their efforts in establishing the Technical and Steering Committees for the project to promote collaboration with the local stakeholders. He indicated that this approach to project implementation was consistent with USAID's policy of "***Aid Effectiveness***" which focussed on promoting ownership by host countries.

He indicated that there was a lot of private sector interest in helping Ghana achieve universal access and expressed his delight at the President's pronouncement at the Africa CEO Forum in Geneva that the private sector will be the driver of the economy. He was hopeful that the workshop would reflect the president's position on effective collaboration between Government and the private sector.

He recounted that through Power Africa, the US Government will continue efforts in partnership with the Government of Ghana to improve energy efficiency, expand use of renewable energy – like mini-grids, provide technical assistance to reform policy and mobilize financing to sustainably develop the energy sector.

Again through IRRP instrument, the US government was helping to build resiliency into power planning in Ghana. He also indicated the commitment of the US Government to support the MESTI in in the resiliency program it was undertaking. He also mentioned PFG as another initiative in which the US Government was collaborating with the Government of Ghana.

Lastly, he pointed out that mini-grids was a great strategy to ensure that the poor have access to electricity to enhance their livelihoods. He recounted evidence of how access to power was directly influencing the livelihood of the poor, particularly in Northern Ghana. Though, a lot had already been done in terms of access, there was still room for improvement. He implored all to contribute significantly to the discussions to ensure that the appropriate recommendations were made to help Ghana advance the sustainable implementation of the mini-grid policies.

He ended by reaffirming the continual support of the US Government to assist Ghana in power planning.

***Comments by Kennedy Mbekeani – Country manager – African Development bank Ghana Office:***

The AfDB Country Manager welcomed all participants on behalf of the Bank and expressed his delight at the number and diversity in participation at the workshop i.e. Civil Society Organizations (CSOs), private sector, Development Partners and the Power Sector Agencies. This he believed, indicated the critical role all these stakeholders played in championing the development of mini-grids in Ghana. He said the African continent was targeting universal access by 2025. In this regard, the Bank was specifically targeting 5 million off-grid connections by 2025 which could only be made possible with such partners. This goal by the AfDB required effective collaboration with all stakeholders to enable it see the light of day. In Ghana in particular the Bank was assisting the country scale-up mini-grids. The Bank’s Sustainable Energy Plan for Africa which was also supported by DFID is leading the Mini-grid Country Support Program. The program aims to improve the needed environment to attract private sector participation in the mini-grid space. The Bank will be coming to Ghana soon with a series of seminars to promote financing of mini-grids in Ghana. Similar efforts were being made in other African countries such as Rwanda, Mozambique, Niger and most recently the Gambia.

He encouraged all to contribute effectively to the discussions to ensure that the workshop were met.

***Keynote Address by the Minister of Energy:***

The key note address of the Minister of Energy was read by Ing. Andrew Barfour, the Coordinator of the GEDAP project at the MoEn. Having acknowledged the presence of the USAID Mission Director and the Country Manager for AfDB, he apologized on behalf of the Honorable Minister for his inability to attend the workshop due to an equally important assignment.

In his submission, he indicated that following the passage of the RE Act in 2011 and the gazetting of attractive feed-in-tariffs, the country had an installed RE capacity of 40MW as of December 2016. He also stated the Ministry’s commitment to increase the current capacity by 10 folds or more by the year 2020; noting that mini-grids would play a significant role in achieving this feat. In 2016, five pilot mini-grid projects were constructed. After successful implementation of the pilot mini-grids projects, and the outcome of a study conducted by Economic Consulting Association (ECA) of the United Kingdom, the MoEn developed and operationalized the public sector-led mini-grid policy that mainstreamed green min-grids into the national electrification generation facility whereas the ECG and NEDCo were responsible for the operation and management of the associated distribution network. Mini-grid customers would pay the same uniform tariff as those on the main grid as well as a zero service connection fee at the time of the project.

In 2017, the MoEn had commenced the development of four additional mini-grids at Alorkpem, Aflivie, and Azizakope all in the Ada East District in the Greater Accra region and Accra-Town in the Pru District of the Brong Ahafo region.

He expressed his confidence that the workshop would examine these policies and strategies and come out with recommendations that would enhance the mini-grid market.

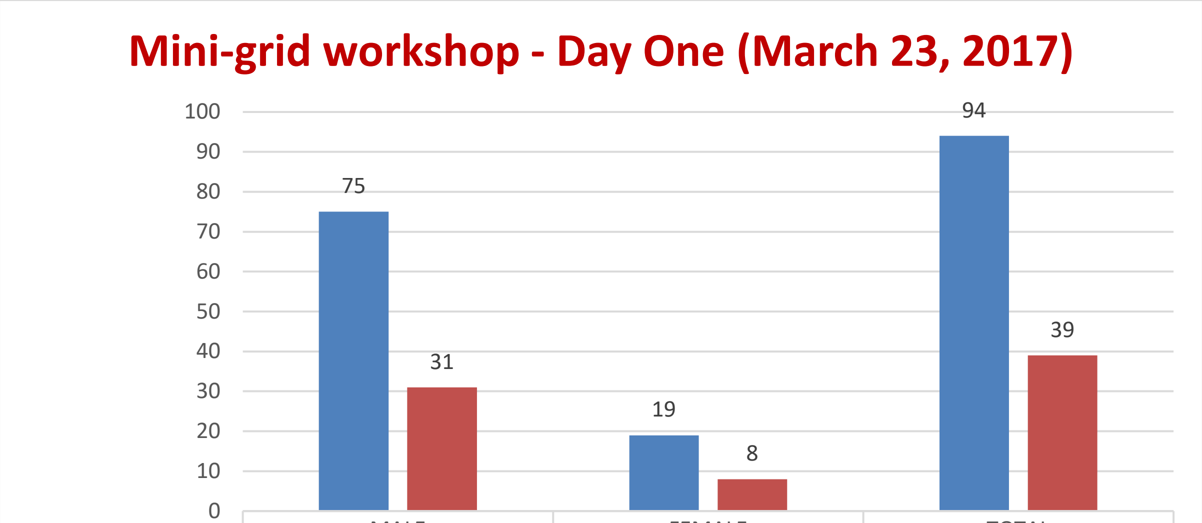
# 2 Attendance

The mini-grid workshop recorded very good attendance from the Government of Ghana (GoG) Agencies, Development Partners (DPs) and Private Sector. The total number of attendees for Day 1 was 94 and that of Day 2 was 45.

## 2.1 Analysis of Participants

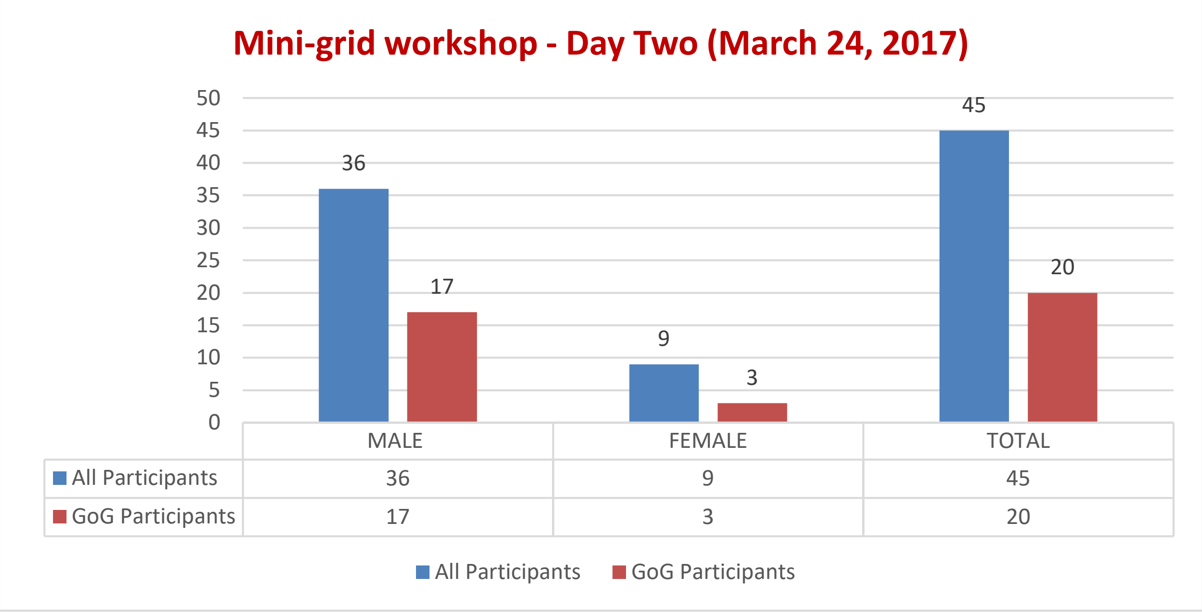
**Figure 1** and **Figure 2** below provide a breakdown of the participants at the workshop for Day One and Day Two respectively.

*Figure 1: Gender Disaggregation of Participants for Day 1*




| | MALE | FEMALE | TOTAL |
|---|---|---|---|
| All Participants | 75 | 19 | 94 |
| GoG Participants | 31 | 8 | 39 |

*Figure 2: Gender Disaggregation of Participants for Day 2*



# 3 Activities for Day One

The main Activities for the first day of the work shop commenced after the opening session. The presentations were captured under three key areas:

- State of Mini-grid in Ghana;
- Private Sector Perspective and Role in Ghana's Mini-grid Scale-up; and
- Regulatory and Commercial Issues – Lessons from Mini-grid Successes in Other Countries.

## 3.1 Highlights of Presentations for Day One

Below provides the key points in the presentations for Day One.

***Table 1: Highlights of Presentations on Day One***

| No. | Topic | Presenter | Highlights |
|---|---|---|---|
| ***Context: State of Mini-grid Policy in Ghana*** | | | |
| 1 | Role of Mini-grids in Electrifying Ghana: Locations, Limitations, Expectations, Financing Timeframes | Director, Renewable Energy; Wisdom Togobo | a. National Electrification Policy -1989<br>b. Rural Electrification<br>c. Rationale For Mini-Grid in Ghana<br>d. Districts With Communities<br>e. Along Volta Lake<br>f. Pilot Mini – Grid Electrification Project<br>g. Highlights Of The 4 Pilot Schemes<br>h. Objective Of The Pilot Mini-Grid<br>i. Criteria For Choice Of Mini Grid<br>j. Mini-Grid Renewable Energy Electrification Policy<br>k. Way Forward Beyond The Pilot Scheme<br>l. Managing Strategy For Mini-Grid<br>m. Financing Strategy<br>n. Way Forward Beyond The Pilot Scheme |
| 2 | Current Regulations On Mini-Grids | Frederick Ken. Appiah | a. Regulatory and Policy Framework<br>b. Regulation before the Mini-Grid Policy<br>c. Licensing Framework for Mini-Grid Policy<br>d. Way Forward |
| 3 | Renewable Energy-Based Mini-Grids For Rural Electrification In Ghana: The State of Demonstration Projects in Ghana | Ing. Seth A. Mahu (Deputy Director, SREP NFP)<br>&<br>Ing. Henry Vanderpuye | a. Objectives for Demonstration Project<br>b. Technical Standards for Physical Infrastructure<br>c. Operational and Management Performance<br>d. Social Acceptability |

| No. | Topic | Presenter | Highlights |
|---|---|---|---|
| | | (GEDAP Access Manager) | e. Conclusions |
| ***Private Sector Perspectives and Role in Ghana's Mini-grid Scale-up*** | | | |
| 4 | Black Star Energy | | a. Who are we?<br>b. BSE Customer-Centred Process & Projects<br>c. Scalability and Reliability<br>d. Affordability<br>e. Regulatory<br>f. Regulatory Wish List |
| 5 | TTA | | a. About TTA<br>b. Pioneers of PV Rural Mini Grids<br>c. Multi-user PV Mini-grids – TTA Background<br>d. GEDAP Mini-grids<br>e. Financial – Economic component →Viability<br>f. Cost structure – understanding capital costs<br>g. Understanding costs… reductions AND increases<br>h. Previous studies – Mini-grid CAPEX<br>i. CAPEX breakdown per component<br>j. OPEX breakdown<br>k. Tariffs in Ghana: cost reflective vs national grid (2016)<br>l. Revenue collection – first 6 months<br>m. Business model validation: Financial gap – first 6 months<br>n. Mini-grid Customers registration – first months<br>o. Take-aways – GEDAP mini-grids<br>p. Lessons learnt in Monte Trigo (Cape Verde)<br>q. Our perspective: private sector shall contribute to all mini-grid delivery models |
| 6 | NGO/Social Enterprise Perspectives | Ishmael Edjekumhene; Executive Director, KITE | a. About KITE<br>b. Nature/Size of the Opportunity<br>c. Delivery Models<br>d. Private Model Will Ensure Faster Roll-Out<br>e. Attracting The Private Sector<br>f. Is The Ghana Mini-Grid Policy Private sector<br>g. Friendly? My Take |

| No. | Topic | Presenter | Highlights |
|---|---|---|---|
| | | | h. Key Questions! |
| ***Regulatory and Commercial Issues: Lessons from Mini-grid Successes in Other Countries*** | | | |
| 9 | Mini-Grids: The Five Big Regulatory / Policy<br>Decisions – the case of Tanzania<br>Eng. Anastas | Eng. Anastas P. Mr. Mbawala | a. Country Overview<br>b. Mini grids in Tanzania<br>• 1. Licensing and Permits (R)<br>• 2. Tariff Setting (R/P)<br>• 3. Quality of Supply and Service (R)<br>• 4. What happens when the main Grid arrives in a mini-grid village? (R/P)<br>• 5. Public Sector Versus Private Sector up or both? (P) |
| 10 | Sharing Off-grid Micro-grids' Experience | Pepin Tchouate Heteu, PATRP Regional Technical Adviser | a. Introduction<br>b. Business & ownership models<br>c. Private sector engagement<br>d. Clear regulations as a pre-requisite for off-grid deployment<br>e. Licensing regulations in selected countries<br>f. Tariff regulations in selected countries<br>g. Compensation & ownership model upon arrival of the national grid |
| | Micro-Grid Experience From East Africa | Ewan Bloomfield | a. Metering and Collection Systems<br>b. Micro-Grid Examples<br>c. Household and Productive Use of Energy<br>d. Quality Assurance Framework<br>e. Financing of Micro-Grids<br>f. Highlights from East Africa |
| | Mini Grids: Exploring Issues Around Grid Encroachment | Emmanuel G. Michael Biririza, Mini-Grid Expert; African Development Bank | a. Mini-Grid Dynamics<br>b. Grid Encroachment<br>c. Grid Encroachment to the Mini-Grid<br>d. Possible Scenarios When Grid Arrives<br>e. Supportive Tools<br>f. The Case of Ghana<br>g. Innovative Approaches<br>h. AfDB puts special emphasis on Enabling environment around Mini-Grid Space |

## 3.2 Key Issues Raised

The following key issues were raised during the Q&A sessions following the presentations.

***Table 2: Key Issues Raised in Discussions***

| No. | Issues Raised | Responses |
|---|---|---|
| 1 | What are the benefits of mini-grids as compared to Solar Home Systems (SHSs)? | ***Black Star Energy (BSE):*** From a cost perspective, the cost per household is nearly the same as the Solar Home Systems. The difference however is that mini-grids can last for up to 20 years whereas home Solar Systems last for about 10 years. Also whereas SHSs will light a couple of light bulbs and a television, the mini-grids take bigger loads like corn mills and light rural enterprises which grow the local economy. Thus in terms of ranking SHSs may be categorized as tier 1 and tier 2 while the mini-grids would fall under tier 3 and tier 4. |
| 2 | How is the Ministry managing the implementation of the uniform tariff policy to ensure that mini-grids are still profitable to encourage private sector participation? | ***BSE:*** The pricing structure of Black Star Energy is different from the Uniform pricing structure. However the prices charged by BSE is comparable or less than what ECG charges.<br><br>***VRA:*** It is imperative to provide a level playing field for both the private and public sector to make the state Agencies profitable. The state Agencies should be given the same incentives given to the private entities. A typical example is the flexibility given to the BSE, which typically would not be given to VRA or any other state Agency. |
| 3 | What is the government's policy on populations below 500? | ***MoEn***: Under the National Electrification Scheme (NES), where the communities are sparsely populated or below 500, they are served with SHSs under a special arrangements where the dwellers pay a portion of the amount over a period of 1 – 3 years depending which option they go for and the remaining portion is a grant. During this warranty period the beneficiaries enjoy free maintenance. This was started under GEDAP and is going to be scaled up under Energy Service Rural Access Project (ESRAP) where the Ministry is targeting about 33,000 SHSs. There is a detailed model which has been used to deliver almost 16000 units of the SHSs.<br><br>***BSE:*** Most of the SHSs break down after a few years because of lack of maintenance and then the MoEn has to look for money again to install new systems. Against this back drop, why can't the MoEn allow private entities to step in and provide the same quality of service to populations under 500 as is being done for those above 500. |

| No. | Issues Raised | Responses |
|---|---|---|
| 7 | ***AfDB:***<br>• What percentage of the operating cost amounts to the management cost?<br>• Does EC have certified technician who are accredited by the EC to ensure that the management cost meets set standards? | ***TTA:*** the management cost is about 30% of the operating cost. |
| 8 | ***USAID:*** BSE got their license from the Energy Commission to construct the mini-grid and charge the tariff. In the light of this:<br>• I would like to know if BSE is being regulated by the PURC since economic regulation is the responsibility of PURC.<br>• Aside from BSE, could another company establish a mini-grid and get the flexibility given to BSE since the policy is uniform tariff? | ***MoEn:***<br>• The current tariff comprise bulk generation tariff (BGT), transmission service charge (TSC) and distribution service charge (DSC). Mini-grid is essentially generation with distribution. So each village has its generation and distribution system. Under the current pricing policy, Bulk generators present their tariffs to PURC for approval. The intention of the public-led model is for VRA to come up with the cost of generating the mini (solar/wind) systems and the likes, in these villages. These costs will be submitted to PURC as part of their generation cost. PURC will have the prerogative to decide whether to apply the feed-in-tariff or use the cost submitted by VRA in determining the uniform tariff. ECG and NEDCo under the current arrangements, when submitting their distribution charges will add that of the mini-grids for approval. Consequently, the mini-grid systems under the public led approach are not considered as isolated requests which require special approval by PURC but rather as an integral part of the tariff request by the utilities. In the light of these, if there are any subsidies, everyone benefits. This is the essence of the uniform tariff policy.<br>• In principle, the EC has not got the mandate to handle tariff in the regulated market. If it is a deregulated customer then the IPP can deal directly with that customer. What the Energy Commission did in the case of the BSE was prior to the policy hence going forward those conditions will not be available and all entities would have to comply with the uniform tariff policy.<br>• Again, currently TTA has been contracted to collect the tariffs on their behalf as part of the pilot project – a typical example of the role that can be played by the private sector. After the completion of the project, this arrangement can continue where ECG and NEDCo can engage the local people to collect the tariffs. |

## 3.3 Activities for Day Two

The activities for Day Two commenced at 9:00 am with a brief recap of activities for Day One by the COP of the IRRP Project. He provided opportunity for pending issues to be addressed before beginning the agenda for day. The activity for Day 2 was essentially to discuss extensively the key issues from Day 1 and make related recommendations for consideration by the Ministry of Energy.

## 3.4 Key Recommendations made

The following key recommendations were made during the discussions.

1) It was agreed that current mini-grids policy can be reviewed and modified, if necessary, to ensure that both public and private sector investments can be utilized for rapid deployment of mini-grids in Ghana.

2) Develop clarity on mini-grid regulations from PURC and EC. E.g., % of complaints, threshold numbers, areas allowed for private sector, timeframe for project development for mini-grids, specific concession agreements,
    a. Rely on existing and updated studies/framework to move ahead (e.g. ECA update)
    b. PURC and EC should share the draft regulations as soon as possible, and hold public consultations on the drafts (would be helpful to develop feasible business models)
        i. There should be minimum acceptable technical requirements for mini-grids
        ii. Collaborate with development partners and other stakeholders with experience in mini-grids deployment for PURC and EC to develop a faster, practical regulatory framework for mini-grids
    c. PURC could consider special tariffs for small-scale RE generation systems that mini-grid systems would be based on. This could help when the grid arrives

3) Clarify from EC on how mini-grids will be impacted by the REPO regulations

4) Clarify the conditions and process for private sector investment
    a. Disclosure of sources of funding
    b. Concession areas/agreements (primarily island and lakeside communities, but mainland areas are also a possibility)
    c. What happens when grid arrives, and when it *should* arrive (e.g. buyout clauses, integration of mini-grids into the grids, become a producer only, meet standards for grid integration that are valid at the time of connections, learn from WB/ESMAP studies)
    d. Any distinction between less than 500 or greater than 500 population centres?
    e. Investment/capital incentives?

5) Need to institutionalize learnings from current mini-grid experiences in Ghana to support regulations and conditions for private sector involvement

6) Develop clarifications (if necessary) on how energy-based services (lighting, industrial services, etc.) – PUE -- would be differentiated from electricity service

## 3.5 Working Session: Questions/Issues

The following questions and issues were also raised during the deliberations.

1. ***Current mini-grid policy (VRA/ECG/NEDCO – led development)***
    a. Limited to mini-grids for 500+ population centres? What options are there for smaller villages? Do they have more flexibility?
    b. How much subsidy is really needed for small (< 500) and large (>500) mini-grids under current PURC tariffs?
    c. How much would the mini-grid subsidies affect PURC tariffs?
    d. What should the role of the private sector be? What policy incentives can attract greater and faster private sector investments?
    e. Procurement options / standardized agreements for mini-grid development?
    f. Dependent on PURC to develop cost-reflective tariffs that include grid-connected costs and mini-grid costs. How will mini-grid operators (private or public) be compensated if that does not happen?
    g. Is there a space for tariff innovation or other subsidy mechanisms under this framework? Who would ensure fairness?
    h. What should VRA/ECG/NEDCO do to prepare to implement current policy? Is Management willing to take on the new risks and deficits? Worries about increased indebtedness?
    i. ECG/NEDCO "taking over collection" – how will this work in practice?
    j. How should VRA/ECG/NEDCO work with the private sector?
    k. Are long term M&O&M contracts for private sector allowed? Contract mechanism? Sustainability?
    l. Asset transfer options under the BOT?
    m. What other sectors and other countries (islands in high income/high electrification rate) can we learn from?
    n. What is the availability of local technical capacity for regulation compliance and mini-grid implementation?

2. ***Options for fine-tuning current policy?***
    a. Policies can change over time

### 3.6 Closing

The Director, Renewable Energy at the MoEn gave the closing remarks for the work shop. He indicated that the work shop had been insightful and generated the discussions on very useful issues related to the implementation of the mini-grid policy. He assured all the participants that the recommendations made at the workshop will be taken seriously by the Ministry of Energy. He also stated that the discussions should not end with the work shop and stated that the doors of the Ministry were still very open to new ideas that would facilitate the sustainable implementation of the mini-grid policy. The workshop was brought to a close at 1:05pm.

# 4 Evaluation of Workshop

The analysis of the feedback from the work shop pointed to a good appreciation of the essence and conduct of the workshop. The details of the evaluation for Day One can be found in **Figure 3** of Annex A. That for Day Two can be found Figure 4 of Annex A.

Annex A also has comments from Day One and Day two in **Table 3** and **Table 4**.

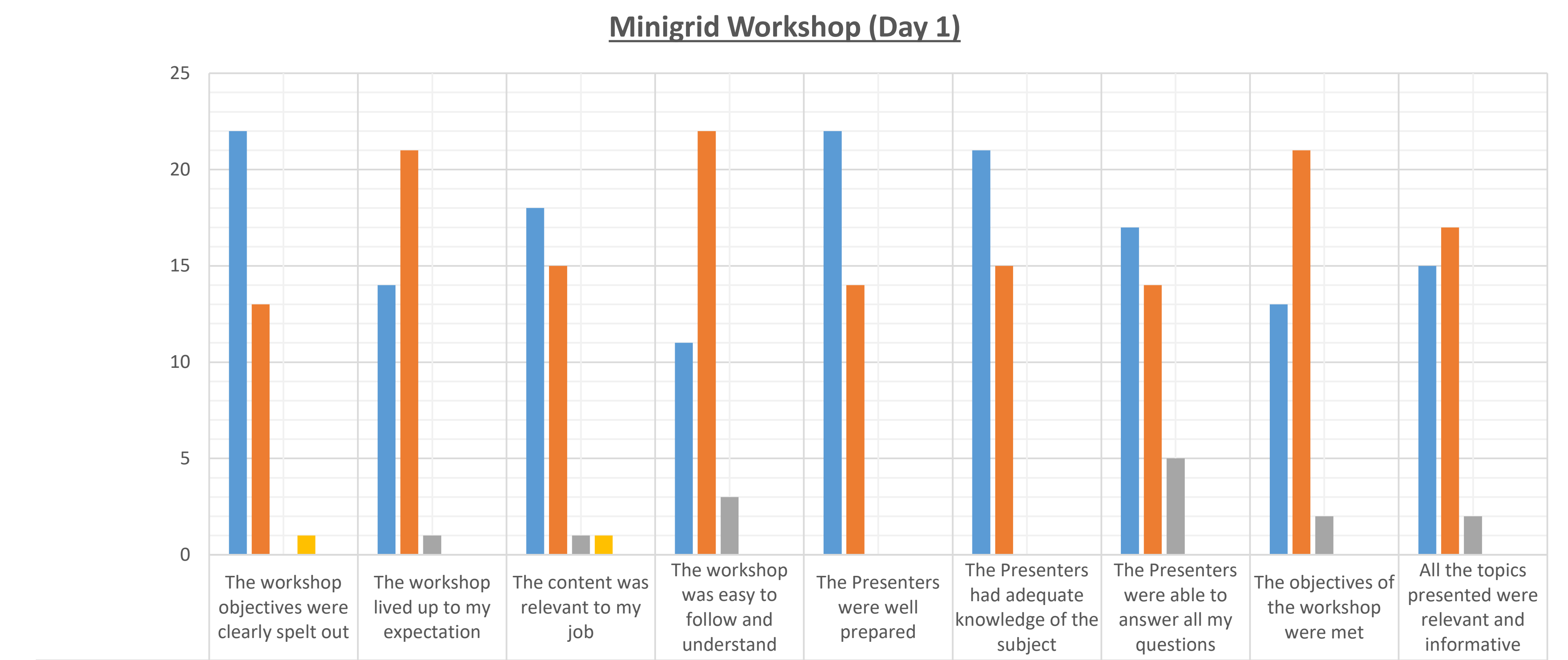
# 5 Conclusion

The Mini-grid workshop was successfully held by ICF in collaboration with the Ministry of Energy, Energy Commission, The World Bank, African Development Bank, USAID and other key stakeholders from March 23 – 24, 2017.

The recommendations from the work shop will be sent to the Minister of Energy in a separate Memorandum for consideration. These recommendations if approved would potentially facilitate the sustainable implementation of the Mini-grid Policy of Ghana.

# 6 ANNEX A: Evaluations

*Figure 3: Analysis of Evaluation for Day One*



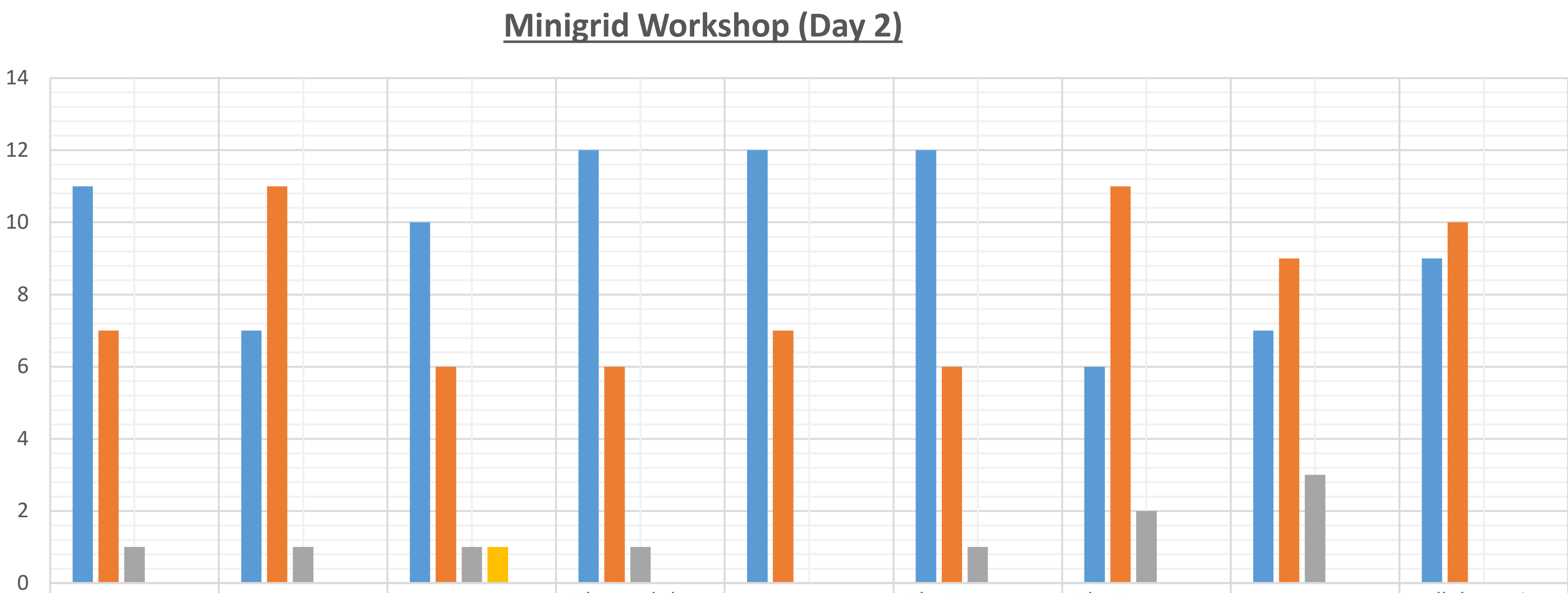

| | The workshop objectives were clearly spelt out | The workshop lived up to my expectation | The content was relevant to my job | The workshop was easy to follow and understand | The Presenters were well prepared | The Presenters had adequate knowledge of the subject | The Presenters were able to answer all my questions | The objectives of the workshop were met | All the topics presented were relevant and informative |
|---|---|---|---|---|---|---|---|---|---|
| Strongly Agree | 22 | 14 | 18 | 11 | 22 | 21 | 17 | 13 | 15 |
| Agree | 13 | 21 | 15 | 22 | 14 | 15 | 14 | 21 | 17 |
| Neutral | 0 | 1 | 1 | 3 | 0 | 0 | 5 | 2 | 2 |
| Disagree | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Strongly Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

***Table 3: Comments from Presentations (Day One)***

| I benefitted the most from | I benefitted the least from | Recommended topics for future workshops | Any other comments |
|---|---|---|---|
| • Presentation by KITE<br>• Discussion expounding on models from other countries: tariff and subsidies are real issues to discuss/debate<br>• Experiences/lessons from mini-grid success in other countries<br>• Overall discussion and presentations<br>• The country presentations<br>• The statistics on mini-grids in Ghana and the areas for expansion<br>• Concrete examples i.e. demonstration projects in Ghana<br>• Presentation by Black Star Energy<br>• Private sector perspective and role in Ghana's mini-grid scale-up<br>• The different case studies<br>• Discussions about tariffs in Ghana<br>• The current mini-grid policy and regulation in Ghana | • Work being done regarding licencing and issuing of permits to private sectors<br>• Presentations about other countries<br>• GOG presentations on mini-grid policy(was a repetition of what we had heard before) | • Mini-grid models need to be explored more and especially the model Ghana is employing may be a challenge to implement<br>• Renewable energy purchase obligation framework<br>• Solar home systems/mini-grid comparison<br>• Financial/funding of projects<br>• Financial and commercial under-pinning's of mini-grid<br>• PPP in energy sector(electricity)<br>• Business models for private sector in line with new policy<br>• Affordability and reliability issues. Universal access to power is useless if there are affordability issues especially, for the rural population | • Discussion has been good and an eye opener<br>• The conference hall was too cold<br>• Interesting to have so many different stakeholders: Public(DPs, GOV), Private(Companies, CSO)<br>• I suggest a 5minute or short break between session to enable participants to stretch and relax<br>• It would be great to stick to the schedule<br>• Good endeavour<br>• The cross-section of participants was very good<br>• In all, the workshop was very informative. I would have like to hear from the PURC on affordability of power in Ghana and whether there are any targeted efforts to address this. It would also be interesting to look at gender differentials in access to electricity in Ghana and Africa as whole |

| I benefitted the most from | I benefitted the least from | Recommended topics for future workshops | Any other comments |
|---|---|---|---|
| • The discussion/presentation on mini-grids in the country by MoEn was beneficial<br>• Presentations by Black Star, TTA and KITE<br>• The good presentations on mini-grids in Ghana and the discussion on the role of the private sector<br>• Regulatory and commercial issues: lessons from mini-grid success in other countries<br>• All the presentations since the issues were clear<br>• The discussion on private participation in mini-grid development as a tool to achieve universal access | | | |

*Figure 4: Analysis of Evaluation of Day Two*




| | The workshop objectives were clearly spelt out | The workshop lived up to my expectation | The content was relevant to my job | The workshop was easy to follow and understand | The Presenters were well prepared | The Presenters had adequate knowledge of the subject | The Presenters were able to answer all my questions | The objectives of the workshop were met | All the topics presented were relevant and informative |
|---|---|---|---|---|---|---|---|---|---|
| Strongly Agree | 11 | 7 | 10 | 12 | 12 | 12 | 6 | 7 | 9 |
| Agree | 7 | 11 | 6 | 6 | 7 | 6 | 11 | 9 | 10 |
| Neutral | 1 | 1 | 1 | 1 | 0 | 1 | 2 | 3 | 0 |
| Disagree | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Strongly Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

***Table 4: Comments from Evaluation of Day Two of Mini-grid Workshop***

| I benefitted the most from | I benefitted the least from | Recommended topics for future workshops |
| --- | --- | --- |
| • All the facilitators<br>• The discussions on the recommendations for off-grid development<br>• Contributions from the experts and the GOG staff. E.g. Experiences shared from other systems<br>• Benefitted most from area of the regulatory framework for the Minigrid operations. Expectation from interested private sector involvement<br>• The current state of regulations and what needs to be done in terms of clear cut criteria to fill the gap<br>• Learned a lot on Minigrid in Ghana<br>• Discussions among the public/state utilities | Conflicting position still embedded in the current policy or lack of clarity in the current Minigrid policy | • The next steps: Universal access to electricity does not mean 90% access across the country. There are special differences with respect to the North and South. What are the next steps to bridging these gaps?<br>• Ways of building technical capacities of staff of utilities in maintenance of off-grid installations/systems<br>• Available projects on renewable energy and the requirement for participation<br>• Detailed discussion-based recommendations<br>• Cost reflective tariffs for the power sector |

# J. Climate Change Risk and Resilience Analysis

As part of the IPSMP and to support the modelling, the IRRP project conducted an analysis of the risks from climate change on Ghana's power sector and the various resiliency options to mitigate these risks.

A summary of the analysis is provided below.

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# GHANA INTEGRATED RESOURCE AND RESILIENCE PLANNING PROGRAM

## Risks And Resiliency In Ghana's Electric Power Sector

OCTOBER 2017

# GHANA INTEGRATED RESOURCE AND RESILIENCE PLANNING PROGRAM

## Risks And Resiliency In Ghana's Electric Power Sector

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# EXECUTIVE SUMMARY

USAID is supporting the Integrated Resource and Resilience Planning (IRRP) project in order to improve longer-term power planning in Ghana and to enhance power system resilience to potential climate change risks. IRRP is a comprehensive approach to help utilities to better plan short- and long-term investments, maintain service delivery during high demand, and preserve supply-side fuel capacity. Through IRRP, infrastructure, electrical generation, and transmission facilities are planned in a coordinated, efficient, and cost-effective manner that considers not only the expected needs for electric service, but also the impacts from climate change.


*Figure 1. Four energy Integrated Planning Model (IPM) and climate assessment zones.*

This report aims to inform Ghana's power system planners and managers of potential climate change uncertainties and associated impacts on the power system. The report also includes information on the types of adaptation measures that could be implemented to address potential climate impacts, and how they can be incorporated into long-term planning to improve power system resilience.

This report provides analysis of potential climate changes and impacts to the power sector at a sub-national scale, in order to better reflect the different climatological zones of the country and to better integrate with the power systems modeling of the larger IRRP project. The four assessment zones, as determined for modeling of the power system using the Integrated Planning Model (IPM), are depicted in Figure 1, above. The Southeast and Southwest zones are wetter and are subject to changes in sea level and storm surge heights, the North zone climate is hottest and driest, and Ashanti has a more moderate climate relative to the extremes of its coastal and northern neighbors.

By mid-century, Ghana's average annual temperature is projected to increase by 1.2 to 1.7°C.[1] Change in annual precipitation is more uncertain, as models disagree on the sign of change. The multi-model averages indicate that there will be minimal changes in total annual precipitation (increases of 1 to 2 percent) but that precipitation will shift, with more rainfall occurring later in the year (October through December) and less occurring during the early part of the usual "rainy season" (April through June). Like rainfall, projections for change in annual runoff and consecutive dry days (a proxy for drought) are mixed in sign and projected to change only minimally, though they are likely to shift in patterns similar to precipitation shifts. 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 m by mid-century.[2]

[1] 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.
[2] 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.

Based on the projected changes in climate conditions, potential impacts on Ghana's power system are identified, including direct and indirect impacts. Direct impacts represent those that directly disrupt the supply of electricity, such as damages to infrastructure from extremes; changes in seasonality or the annual amount of streamflow entering hydropower reservoirs; or temperature increases that reduce transmission and distribution efficiency. Indirect impacts are those impacts "facilitated" by climate stressors, for example, erosion and reservoir sedimentation due to intense precipitation events or loss of transmission towers due to fire (facilitated by an ongoing extreme dry and/or warm event).

These direct and indirect climate change impacts, not surprisingly, have implications on power planning. For example, the ultimate choice and timing of power investments could be influenced by climate impacts across the power system. In effect, IRRP is designed to take into account potential risks that may affect resources, capacity additions, and resource costs and prices, in order to inform power system investments and planning over time.

Of the power system components, transmission and distribution infrastructure are particularly at risk to a range of climate impacts, especially assets located in low-lying coastal areas that may be exposed to rising sea level and storm surge heights, as well as increases in extreme rainfall, and temperature (see Table 1, below). Taken in combination, projected increases in extremes (drought, flood, or heatwaves) have the greatest potential to impose negative impacts across the power system because they are likely to increase demand while diminishing generation (in particular, hydropower) as well as transmission and distribution capacity. At the same time, there may be beneficial opportunities, such as increasing solar capacity due to an increase in irradiation.

**TABLE 1. 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

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 materialize.[3] Types of adaptation measures include policy and planning, operation and maintenance, technological, and structural measures.

Power planners need to recognize limitations and uncertainties when gathering and applying climate information to inform their decision making and investments. In Ghana, climate change projections are particularly uncertain for future changes in annual precipitation and runoff volumes, though there is higher confidence on projections of more frequent and intense rainfall which may lead to flooding. In addition, there is a lack of available, accessible, and useful data to conduct meaningful climate analysis in many locations in Ghana. However, uncertainty or lack of complete data is not a reason for inaction. Rather, there is a need to plan robust strategies to prepare for uncertain futures.

With that in mind, the IRRP process is being applied in Ghana in order to identify and assess the performance of different investment strategies in the power sector, given different growth and risk scenarios (including climate), in order to inform a new "least-regrets" resource plan, which will then inform the power system master plan. A least-regrets plan assesses the performance of potential power system investments given a range of important metrics (e.g., cost, feasibility, load served, greenhouse gas emissions), allowing power sector planners to compare different investment performance against different objectives given potential future uncertainties.

## INTRODUCTION

Ghana's National Climate Change Adaptation Strategy highlights the energy sector as a priority area for adaptation.[4] Among the strategy's ten priority adaptation programs is the development of demand- and supply-side measures for adapting the energy system to the impacts of climate change.[5] The strategy also recognizes the ties between water and energy, calling for increased accessibility of water for energy production. To carry out the strategy and effectively enhance resilience in the energy system, Ghana's power sector decision makers must have a clear understanding of the potential risks and uncertainties that the sector faces.

Ghana's infrastructure and economy have already begun to experience impacts from a changing climate, including impacts from rising sea levels, increased storm surges, extreme rainfall, and flooding, and increased frequency and severity of drought.[6,7,8,9] The electricity sector has particularly begun to feel the impacts of highly variable precipitation on hydropower.[10]

[3] World Bank. 2009. Water and Climate Change: Understanding the Risks and Making Climate-Smart Investment Decisions.
[4] UNEP and UNDP. 2016. National Climate Change Adaptation Strategy. Cliamte Change and Development – Adapting by Reducing Vulnerability (CC DARE).
[5] UNEP and UNDP 2016
[6] Boateng, I., Wiafe, G., & Jayson-Quashigah, P. N. (2017). Mapping vulnerability and risk of Ghana's coastline to sea level rise. Marine Geodesy, 40(1), 23-39.
[7] Bekoe, E. O., & Logah, F. Y. 2013. The impact of droughts and climate change on electricity generation in Ghana. Environmental Sciences, 1(1), 13-14.
[8] Boateng, I. 2012. An assessment of the physical impacts of sea-level rise and coastal adaptation: a case study of the eastern coast of Ghana. Climatic Change, 114(2), 273-293.
[9] World Bank. 2010. Economics of Adaptation to Climate Change: Ghana.
[10] World Bank 2010

The National Climate Change Adaptation Strategy highlights the power sectors heavy reliance on hydropower, and the vulnerability of hydropower to decreased water availability. To combat this vulnerability, the strategy calls for the diversification of its power supply mix. However, power sector stakeholders must also recognize and internalize the risks that climate change imposes on new non-hydropower generation investments, as well as risks to transmission and distribution, and impacts on energy demand.

To better understand and address these potential risks and uncertainties in longer-term power planning, USAID is supporting the Integrated Resource and Resilience Planning (IRRP) project. Traditional Integrated Resource Planning (IRP) is an iterative and participatory planning process commonly applied to identify energy options that serve the highest possible public good and provide benefits such as ensuring energy security, reducing sector inefficiencies, and reducing electricity costs. IRRP is an adapted version of IRP that incorporates climate risk management. This project applies IRRP to Ghana's power system to identify and assess potential risks and uncertainties, and the types of approaches and technologies that could be implemented in order to enhance system resilience. IRRP considers the entire power system (supply and demand), and is supported by detailed assessments involving numerical models (e.g., use of ICF's Integrated Planning Model (IPM)™ to evaluate alternative scenarios and power system investment strategies). Ultimately, the IRRP assessment will be used to inform the development of a new power system master plan.

This report is organized in four sections that inform Ghana's power planners on:

1) How climate is projected to change in Ghana, including at a sub-national level: This report presents a range of potential climate changes for different variables and stressors at mid-century, given "low" and "high" greenhouse gas emissions scenarios, to reflect future climate change emission uncertainties.
2) The types of climate risks, uncertainties, and potential impacts to the power sector that planners need to be aware of and plan for. This report identifies a range of potential climate change impacts given "low" emission and "high" emission projections.
3) The types of climate risk management options that can be used to mitigate or reduce these potential impacts, including for power generation, transmission and distribution, and demand.
4) The integration of climate change into the IRRP approach for building climate resiliency into power systems planning.

The information presented in this report will be used to inform stakeholder deliberations during a risk and resiliency workshop to help identify critical climate risks and the associated climate change stressors that should be taken into consideration in the broader IRRP process. This may be undertaken through the development of climate scenarios to include in the modeling of hydropower assets, or through more qualitative consideration and integration into the power system master plan.

# OVERVIEW OF CURRENT AND PROJECTED CLIMATE IN GHANA

To provide a more granular analysis of projected climate impacts and enable results to more easily integrate into the integrated energy planning modeling, the country was divided into four zones matching the four IPM nodes. These include North, Ashanti, South-East, and South-West, as shown in Figure 2, right.

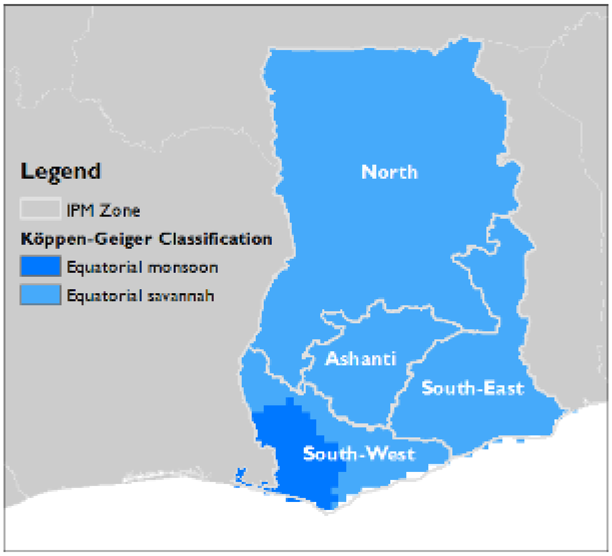



*Figure 2. Ghana IPM zones and climate classifications.*

Ghana's climate is primarily equatorial savannah (light blue in Figure 2, right) characterized by distinct rainy and dry seasons, where precipitation mainly occurs during the rainy season. The southwestern tip contains an area of equatorial monsoon (dark blue in Figure 2), characterized by heavy rainfall and high temperatures with minimal annual variation.

The following section describes Ghana's historical and projected temperature, precipitation, and sea level change. These climate projections have been derived from publicly available climate resource aggregators, including: the Koninklijk Nederlands Meteorologisch Instituut's (KNMI) Climate Explorer,[11] the World Bank's Climate Change Knowledge Portal (CCKP),[12] and the Nature Conservancy's ClimateWizard[13]. All of these resources include some historical climate information, and climate change projections from a large set of peer-reviewed Intergovernmental Panel for Climate Change (IPCC) models that can be tailored by greenhouse gas emissions scenario and location. The type of climate parameters, accessibility of data, and geographic tailoring differs across the tools.

**Box 1. Characterizing Climate Change: Climate Parameters and Scenarios**

This report looks at risks associated with the primary climate parameters that impact the energy sector, including temperature; rainfall; water flow, volume, and timing; drought; and sea level rise and storm surge.

To estimate changes in climate parameters, the report compares the historical period (1986 – 2015, unless otherwise noted) against the future mid-century period (2040 – 2059, unless otherwise noted). To account for uncertainty in greenhouse gas emissions, the report considers both "low" and "high" emissions scenarios. The "low" scenario is represented by the representative concentration pathway (RCP) 4.5, and the "high" scenario is represented by RCP 8.5, both of which are based on the 2014 Intergovernmental Panel on Climate Change (IPCC) fifth Assessment Report (AR5). The report uses the mean model ensemble projection, meaning the mean of the values associated with a collection of model simulations which characterize a climate projection.

[11] Verver, Ge and Jan van Oldenborgh, Geert. (2015). KNMI Climate Explorer and the International Climate Assessment & Dataset (ICA&D), Royal Netherlands Meteorological Institute, United Nations Framework Convention on Climate Change. https://climexp.knmi.nl
[12] The World Bank. Climate Change Knowledge Portal. http://sdwebx.worldbank.org/climateportal/
[13] The Nature Conservancy, ClimateWizard. http://www.climatewizard.org/

## TEMPERATURE

Average annual temperature is similar for the three southern zones (27°C), and slightly higher for the North (28°C). In all zones, temperature exhibits a bimodal pattern, with a peak in February/March, a dip in August, and a smaller peak in November, as seen in Figure 3. This seasonal variation in temperature is greatest in the North.[14]

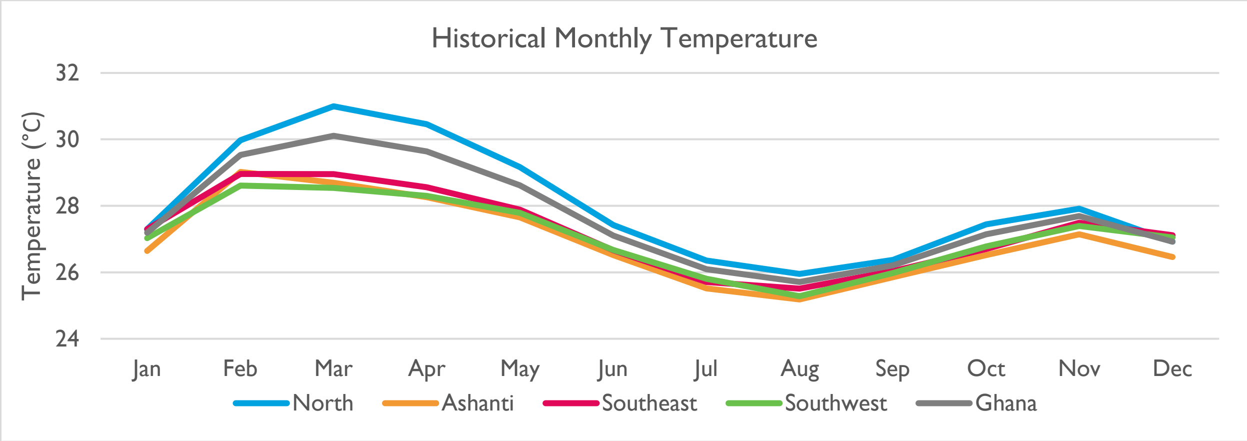



*Figure 3. Historical (1986-2015) monthly temperature. Source: KNMI Climate Explorer; CRU TS 4.0*

Cooling degree days, or CDD, is a metric used to estimate electricity demand based on temperature. CDD refers to the number of degree days exceeding 18°C, the point at which air conditioning is typically turned on,[15] increasing electricity demand. The seasonal pattern of historical monthly CDD in Ghana and each of the zones follows a pattern similar to historical temperature, with a peak in March, dip in August, and a less intense peak in November.

Since the 1960s, temperature has increased by an average of 0.2°C per decade. This increase has been similar in all regions, but slightly higher in the North and lower in the Southwest.

By mid-century, average annual temperature is projected to increase by 1.3 to 1.8°C in the North and by 1.2 to 1.6°C in the other three zones, as shown in Figure 4. Projected temperature increases are broadly consistent across the models.[16]

[14] Please note that figures 2 and 3 are based on Climatic Research Unit Time Series (CRU TS) monthly time series gridded data, based on individual weather station records, with varying coverage within the regions. These trends may vary at specific locations, and should be interpreted with caution.
[15] The 18°C threshold is typical for more developed countries with temperate climate, the threshold may be higher in Ghana due to higher heat tolerance, and lower incomes. Still, the trend of increasing cooling demand is relevant.
[16] Based on mid-century (2040-2059) RCP 4.5 and RCP 8.5 projections from Climate Change Knowledge Portal.

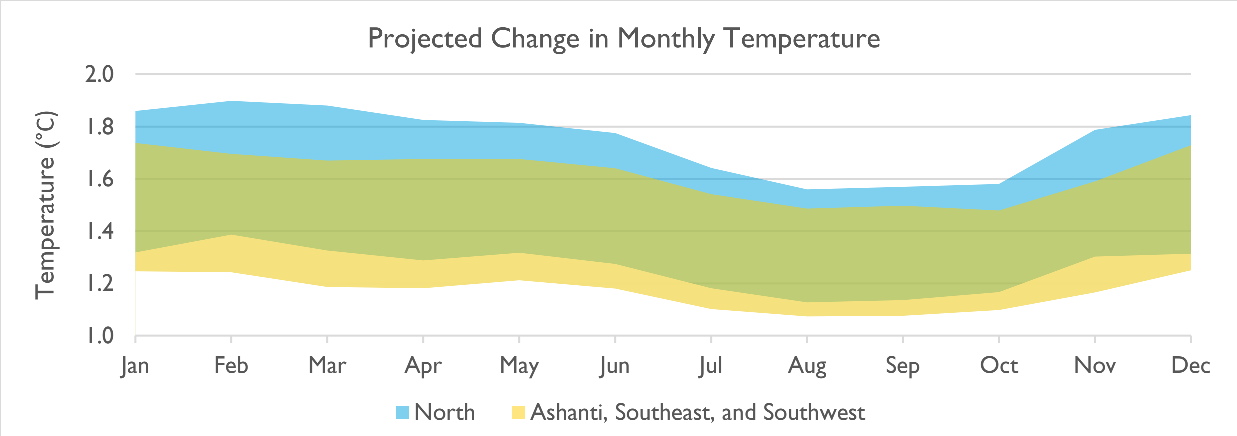



*Figure 4. Projected (2040-2059) change in monthly temperature relative to 1986-2015. The lower bound of the colored ranges represent the RCP 4.5 ensemble average, while the upper bounds represent the RCP 8.5 ensemble average. Source: KNMI Climate Explorer; CMIP5*

Following the temperature increase, CDD are projected to increase by 16 percent to 21 percent under a low emissions scenario and by 20 to 27 percent under a high emissions scenario by mid-century.[17] As illustrated in Figure 5, below, all zones are projected to undergo similar changes in CDD.

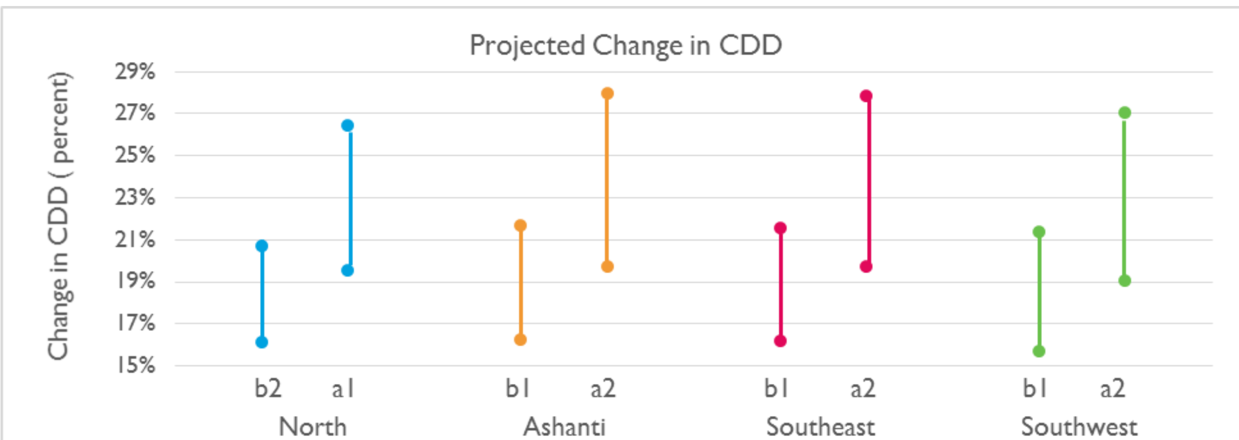



*Figure 5. Projected (2046-2065) change in CDD under low emissions (b1) and high emissions (a2) emissions scenarios relative to 1961-1999. Ranges represent the 25th to 75th percentiles of models. Source: Climate Wizard*

[17] Low-emissions scenario refers to the b1 scenario, high emissions scenario refers to the a2 scenario. Ranges represent 25th to 75th percentile values of models. Mid-century refers to 2046-2065. Source: Climate Wizard.

## RAINFALL

In Ghana, rainfall seasons are dictated by the inter-tropical convergence zone (ITCZ) which swings between the northern and southern hemispheres during the year, as shown in Figure 6.[18] South of the ITCZ, southwesterly winds are dominant, bringing humid ocean air inland. North of the ITCZ, northeasterly winds are dominant, bringing harmattan, or hot, dusty air from the Sahara. As the ITCZ moves, areas between the southernmost and northernmost positions experience a change in dominant wind direction, a pattern known as the West African Monsoon.[19]

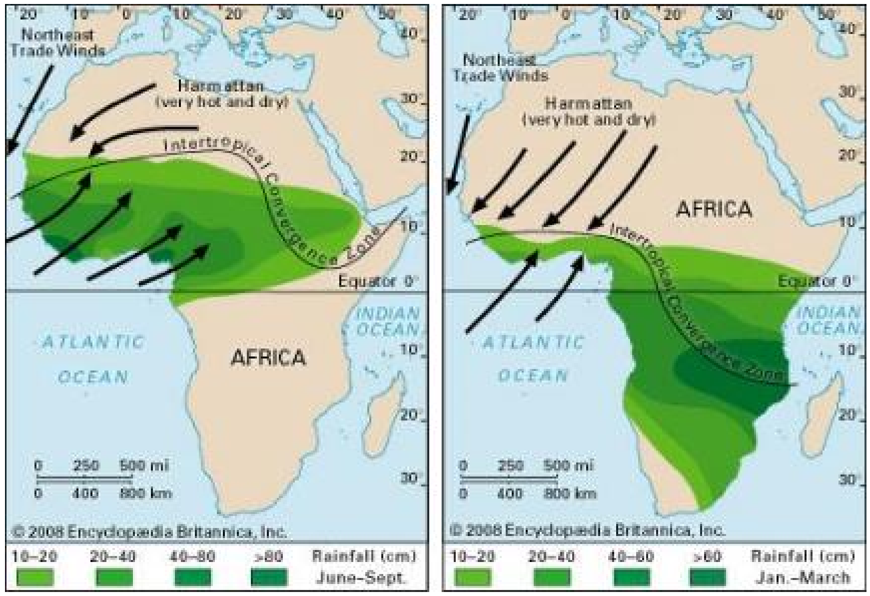



*Figure 6. The West African Monsoon, including Inter-tropical Convergence Zone (ITCZ), wind, and rainfall patterns for June-Sept (left) and Jan-Mar (right). Source: Encyclopedia Britannica*

Due to this phenomenon, northern Ghana experiences a single wet season between May and November, during which the ITCZ is in the northern position, and a dry season from December to March, dominated by northwesterly harmattan winds, as shown by the blue series in Figure 7, below. Meanwhile, the southern, coastal areas experience two annual passages of the ITCZ, leading to a bimodal precipitation pattern, with one rainy season occurring March to July and a second, shorter one occurring September to November, as shown by the orange, red, and green series in Figure 7.[20]

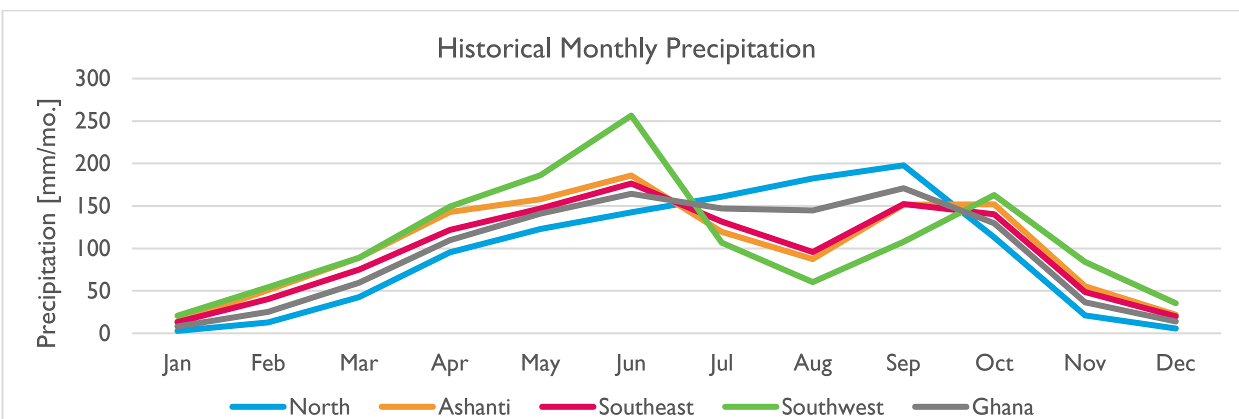



*Figure 7. Historical (1986-2015) monthly average precipitation by zone and for the entire country. Source: KNMI Climate Explorer*

[18] Smith, P., Gentilli, J., and Krishnamurti, T. West African Monsoon. In Encyclopedia Britannica.
[19] McSweeney, C., New, M., and Lizcano, G. UNDP Climate Change Country Profiles: Ghana.
[20] McSweeney et al. n.d.

According to Climatic Research Unit Time Series (CRU TS) monthly gridded data, from 1901 to 1960, average annual precipitation increased by about 15 mm per decade; since the 1960's, average annual precipitation has declined by about 23 mm per decade. According to the data, the Southwest has experienced the greatest decrease in rainfall (~46 mm per decade) while the North has experienced the least change. However, the decrease in total annual precipitation from 1961 to 2015 is not statistically significant, with the exception of the Southwest zone.[21] Please note that due to the nature of CRU TS data, these figures rely on a few individual weather station records; thus, these trends may vary at specific locations, and should be interpreted with caution.

Future precipitation change is uncertain, as models disagree on the magnitude and sign of change (whether there will be an increase or decrease).[22] More specifically, simulations for the Sahelian and Guinea coasts of Africa diverge strongly and fail to simulate realistic annual and decadal variability.[23] The models significantly disagree on the projected amplitude of El Niño events, which strongly influence the West African climate. To better understand model responses in the region, more research on the processes causing tropical rainfall is needed, according to the IPCC.[24]

However, there is more consensus across the climate model projections (particularly under the RCP 4.5 emissions scenario) that seasonal precipitation patterns will shift. The model ensemble averages for RCP 4.5 and RCP 8.5 indicate a projected shift in precipitation, with more precipitation falling during the latter part of the rainy season through the beginning of the dry season, and less falling during the early part of the rainy season, as shown in Figure 8, below. More specifically, the North is projected to experience a 3 to 5 percent increase from July to January and a 2 percent decrease from February to June, with a 1 to 2 percent increase in total annual precipitation.[25] While Ashanti, the Southeast, and the Southwest are projected to experience a 2 to 5 percent increase from July to January, and a 2 percent decrease from February to June, with a 1 to 2 percent increase in total annual precipitation.

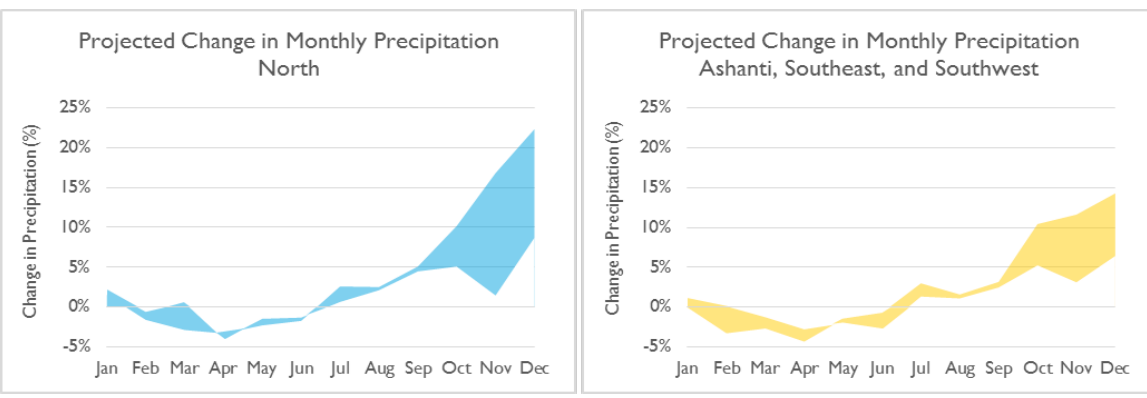



*Figure 8. Projected (2040-2059) change in monthly precipitation relative to 1986-2015. The lower bound of the colored ranges represent the RCP 4.5 ensemble average, while the upper bounds represent the RCP 8.5 ensemble average. Source: KNMI Climate Explorer.*

[21] Using an alpha value of 0.05
[22] Based on mid-century (2040-2059) RCP 4.5 and RCP 8.5 projections from Climate Change Knowledge Portal.
[23] McSweeney et al., 2010
[24] McSweeney et al., 2010
[25] Ranges represent ensemble averages for RCP 4.5 and RCP 8.5 for 2040-2059. Source: KNMI Climate Explorer.

There is more model agreement regarding changes in extreme precipitation. Models indicate an increase in the amount of precipitation occurring on days where precipitation exceeds the 99th percentile. The North is projected to experience a 24 to 26 percent increase and the other three zones are projected to experience an 18 to 25 percent increase in the amount of precipitation that occurs during 99th percentile extreme precipitation events.[26]

## WATER FLOW, VOLUME, AND TIMING

Due to high variability in the temporal and spatial distribution of precipitation in the Volta Basin, there is a high degree of seasonal, inter-annual, and spatial variability in runoff.[27] Much of the runoff is concentrated from July to November, as illustrated in Figure 9, below.[28] In the northern Volta River Basin, low rainfall and high potential evaporation causes rivers to dry up during the dry season. In the south, with higher rainfall and lower potential evaporation, rivers are perennial. However, lower rainfall amounts over the years due to longer dry seasons have led to more and more tributaries as well as main rivers drying up quickly, leading to lesser amounts of surface and ground waters available.[29]

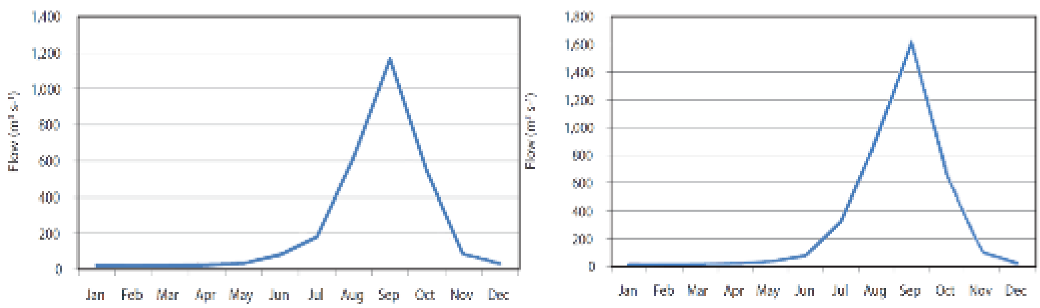



*Figure 9. Historical (1983-2009) observed average monthly flow hydrographs in the Volta Basin. Left: Flow for Nawuni on the White Volta. Right: Sabari on the Oti River. Source: Modified from McCartney et al. 2012*

Volta Basin river discharge patterns follow precipitation patterns with a lag of 1 to 2 years, as shown in Figure 10, below.[30] In recent years, net annual precipitation has declined (-15 mm/year for from 2002 to 2014), as have water levels in Lake Volta (which is formed by the Akosombo Dam).[31] Typically, wet and dry periods occur on a 4- to 5-year cycle. However, the Basin has recently experienced long dry periods, such as the period from 2001 to 2007.

[26] Ranges represent ensemble averages for RCP 4.5 and RCP 8.5 for 2040-2059. Source: KNMI Climate Explorer.
[27] Amisigo, B. A., McCluskey, A., & Swanson, R. (2015). Modeling impact of climate change on water resources and agriculture demand in the Volta Basin and other basin systems in Ghana. Sustainability, 7(6), 6957-6975.
[28] Amisigo et al. 2015
[29] Andah EI, van de Giesen N, Biney CA (2003) Water, climate, food, and environment in the Volta Basin. Adaptation strategies to changing environments. Contribution to the ADAPT project
[30] Ndehedehe, C., Awange, J., Kuhn, M., Agutu, N., & Fukuda, Y. 2017. Analysis of hydrological variability over the Volta river basin using in-situ data and satellite observations. Journal of Hydrology: Regional Studies, 12, 88-110.
[31] Ndehedehe et al. 2017

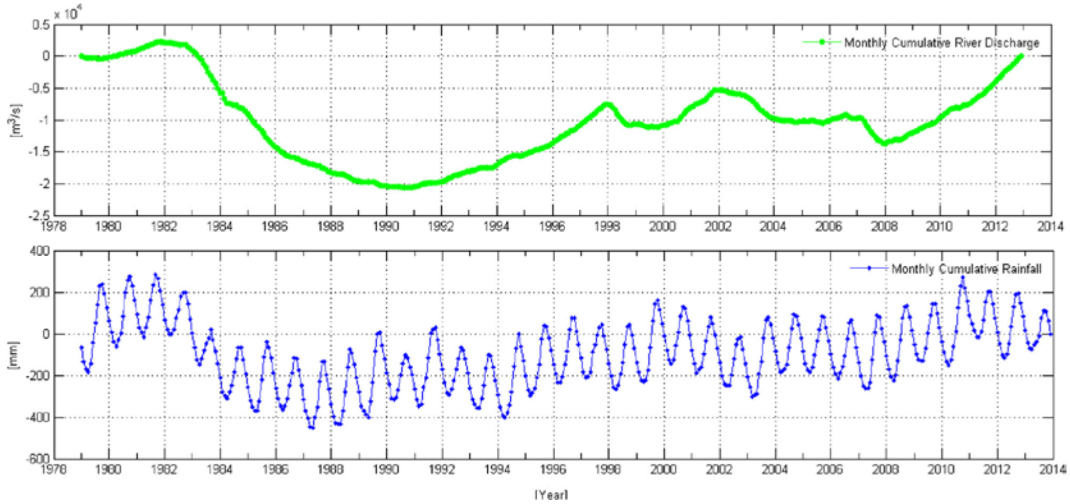



*Figure 10. Historical cumulative monthly rainfall (bottom) and river discharge (top) averaged over the Volta Basin 1979-2013. Source: Ndehedehe et al. 2017.*

In terms of spatial distribution, historically the average annual flow is highest in the Lower Volta basin (1200 m3/s) and lowest in the Southwest region of the country, as shown in Figure 11, below, left. Hydrologic models are typically used in combination with climate model projections of rainfall, temperature (and other factors) to produce projected changes in runoff. Given the importance of rainfall as a driving factor of runoff, the changes in runoff under climate change are similar in character to the rainfall projections, with some uncertainty in terms of the sign of change. Temperature increases primarily effect runoff by increasing the potential evapotranspiration, which can be significant as a result of agricultural demand. Amisigo et al. (2015) project that mean annual flow will decrease by 8 to 26 percent under a Ghana dry scenario, and increase by 0 to 72 percent under a Ghana wet scenario by 2030 (Figure 11, below center and right).[32] Similarly, Poyry and ECOWAS ECREE (2017) used a water balance model to simulate future runoff, including the combined effects of future rainfall and considerable warming, finding the sign of future change in runoff is uncertain.

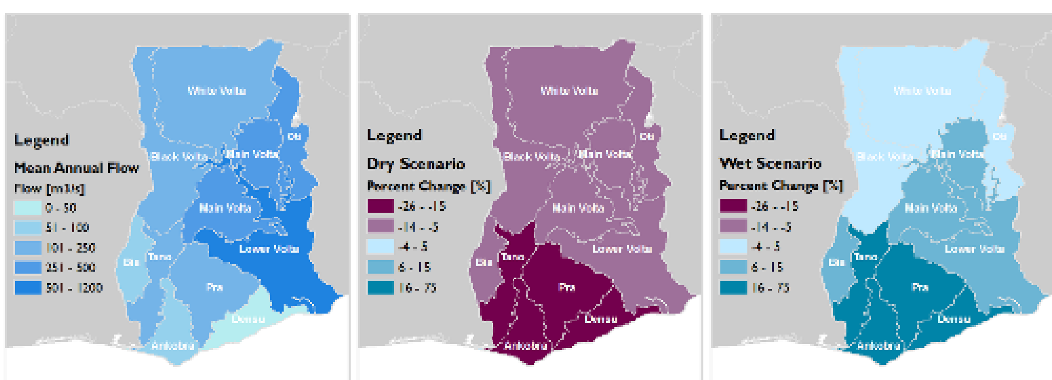



*Figure 11. Left: Observed mean annual flow in cubic meters per second by sub-basin. Center: Projected percent change in mean annual flow under a Ghana dry scenario by 2030. Right: Projected percent change in mean annual flow under a Ghana wet scenario by 2030. Source: Data from Amisigo et al. 2015.*

[32] Projections for 40-year period centered around 2030 relative to 50-year period centered around 1975

Similarly, projections based on 15 Regional Climate Models from the CORDEX-Africa ensemble and two emissions scenarios (RCP 4.5 and RCP 8.5) indicate that by early and mid-century (2035 and 2055), the inner quartile of discharge projections will change by ±10% in the Black Volta, Pra, and Oti rivers within the Volta Basin, as shown by the blue boxes in Figure 12, below.[33] The median indicates slight reductions by in the near term, but is closer to the reference period (no change) at mid-century. However, as indicated by the whiskers (black bars) there is a wide range in model results, with uncertainty increasing from near term to mid-century.

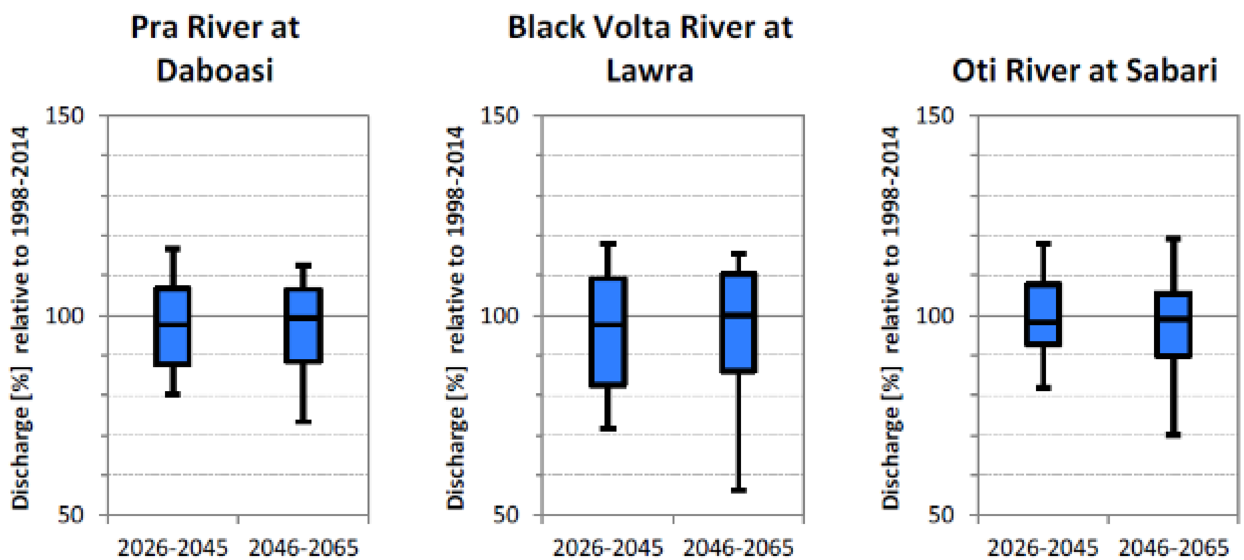



*Figure 12. Projected change in discharge in the Pra, Black Volta, and Oti rivers by 2026-2045 and by 2046-2065 relative to 1998-2014. Source: Poyry and ECOWAS ECREE 2017.*

## DROUGHT

Drought is a function of rainfall and temperature conditions. In West Africa, seasonal rainfall varies substantially on annual and decadal scales, partly due to fluctuations in ITCZ movements and intensity, and associated variations in timing and intensity of the West African Monsoon.[34] Rainfall variations are largely driven by the El Niño Southern Oscillation (ENSO); El Niño years are associated with drier than normal conditions.[35] Due to the high seasonal and inter-annual variability in precipitation and high rates of potential evapotranspiration, Ghana has a history of drought. The Volta Basin, which covers 64 percent of Ghana[36] and holds all three hydropower dams, has historically experienced drought years and rainfalls nearing drought years, including 1977, 1983, 1988, 1992, 1998, 2001, and 2006 as shown in Figure 12.[37] Four out of seven of these (1983, 1988, 1992, and 1998) were El Niño years.[38]

[33] Poyry and ECOWAS ECREEE. 2017. GIS Hydropower Resource Mapping and Climate Change Scenarios for the ECOWAS Region, Country Report for Ghana. ECOWAS Center for Renewable Energy and Energy Efficiency (ECREE).
[34] Global Security. Togo-Environment. http://www.globalsecurity.org/military/world/africa/to-climate.htm
[35] Global Security. Togo-Environment. http://www.globalsecurity.org/military/world/africa/to-climate.htm
[36] FAO. The Volta Basin. http://www.fao.org/docrep/W4347E/w4347e0u.htm
[37] Bekoe and Logah 2013
[38] NOAA. El Niño Southern Oscillation (ENSO) Past Events. https://www.esrl.noaa.gov/psd/enso/past_events.html

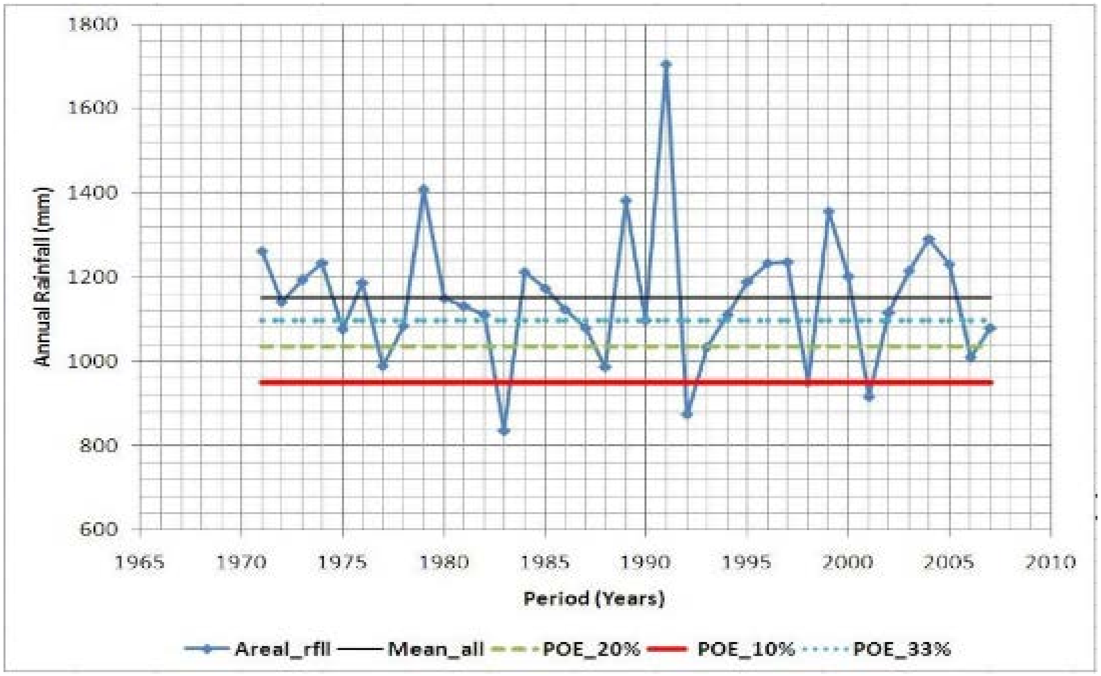



*Figure 13. Volta River Basin historical rainfall and annual drought years (exceeding probability of exceedance [POE] 10 percent, depicted by the red line) and nearing drought years (exceeding POE 20 percent, depicted by the green dash). Source: Bekoe and Logah 2013.*

The Palmer Drought Severity Index (PDSI), a drought indicator, shows that Ghana has experienced increasing drought since the 1960's (seen in Figure 14) though this trend is not statistically significant.[39]

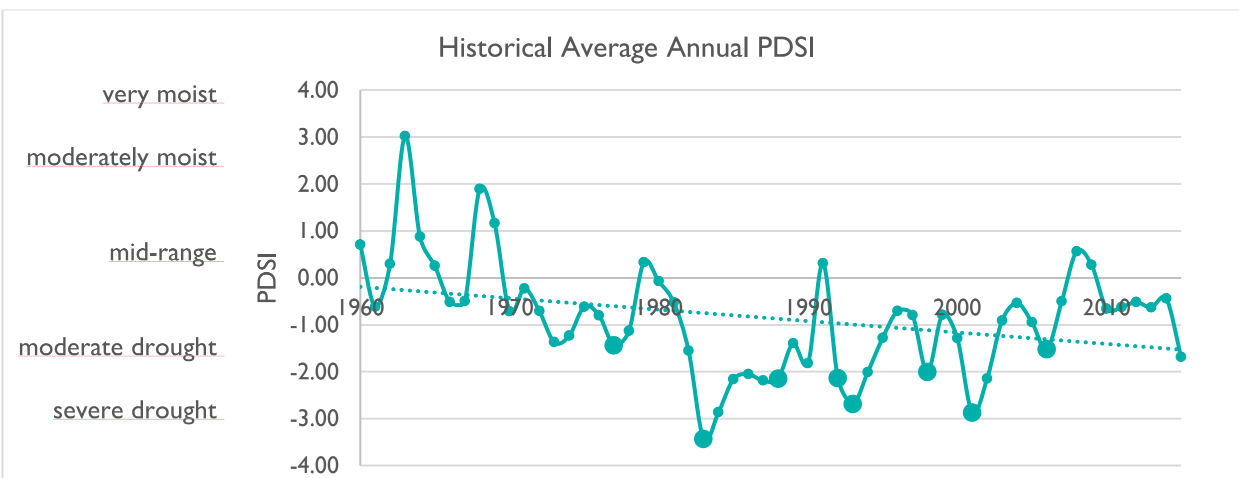



*Figure 14. Historical (1960-2015) average annual PDSI in Ghana. Aforementioned Volta drought years are depicted by larger teal points. Source: KNMI Climate Explorer*

[39] Using an alpha value of 0.05

Total annual precipitation is generally highest in the equatorial monsoon climate of the coastal southwest, and decreases from south to north, as shown in Figure 15, below.[40] In contrast, potential evapotranspiration is generally lowest in the southwest and highest in the inland areas (Figure 15).[41] Though Ghana receives high volumes of rainfall, much of it is lost via evapotranspiration. In central Ghana, 85 percent of precipitation is lost through evapotranspiration, while the other 15 percent ends up as runoff. In northern Ghana, around 90 percent is lost to evapotranspiration while 10 percent becomes runoff.[42] Similarly, total moisture content has historically been higher in the North than in the other zones. Both areas experience a peak in soil moisture content in September and October, and a dip in March and April.[43]

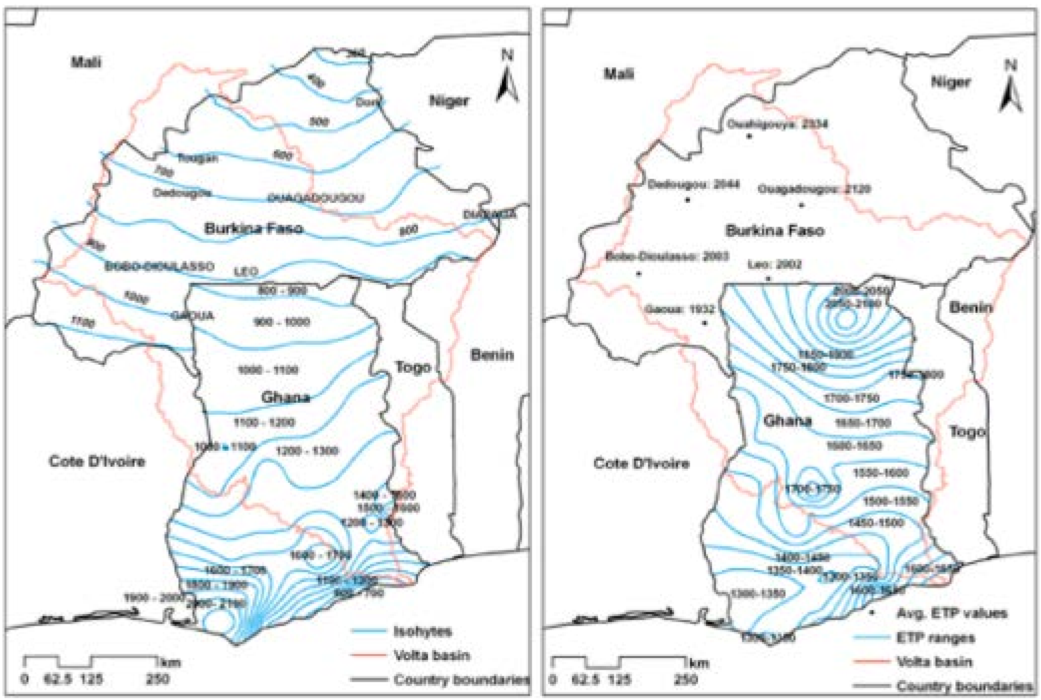



*Figure 15. Left: Annual precipitation (mm). Right: Potential evapotranspiration. Source: Amisigo et al. 2015*

Total soil moisture content is projected to increase throughout the year in all zones, with average annual soil moisture content increasing by 2 percent in the North and by 2 to 4 percent in all other zones. [44] As illustrated in Figure 16, below, the greatest increases coincide with the greatest projected precipitation increases, being October to December in the North and November to January in the other zones.

[40] Amisigo, B. A., McCluskey, A., & Swanson, R. (2015). Modeling impact of climate change on water resources and agriculture demand in the Volta Basin and other basin systems in Ghana. Sustainability, 7(6), 6957-6975.
[41] Amisigo et al. 2015
[42] Poyry and ECOWAS ECREEE. 2017. GIS Hydropower Resource Mapping and Climate Change Scenarios for the ECOWAS Region, Country Report for Ghana. ECOWAS Center for Renewable Energy and Energy Efficiency (ECREE).
[43] KNMI Climate Explorer
[44] Values represent ensemble averages for RCP 4.5 and RCP 8.5 for 2040-2059 relative to the historical period 1986-2015. Source: KNMI Climate Explorer.

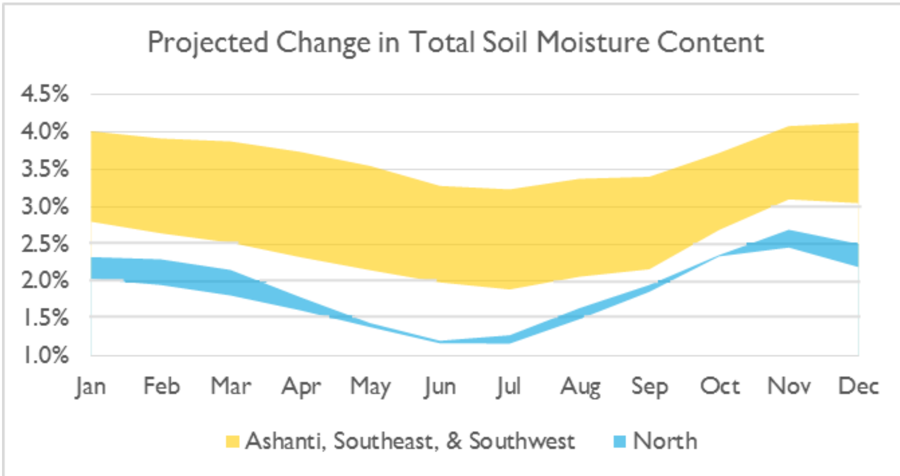



*Figure 16. Projected (2040-2059) percent change in total soil moisture content relative to the historical period of 1986-2015. Source: KNMI Climate Explorer*

There is more uncertainty in the sign of change of consecutive dry days. By mid-century, consecutive dry days are projected to change by -0.7 to +0.7 percent in the North, and increase by 0.8 to 1.1 percent in Ashanti, the Southeast, and the Southwest.[45] Under the high climate change scenario, dry spell duration in Accra is projected to increase in most months, as illustrated in Figure 17, below.[46]

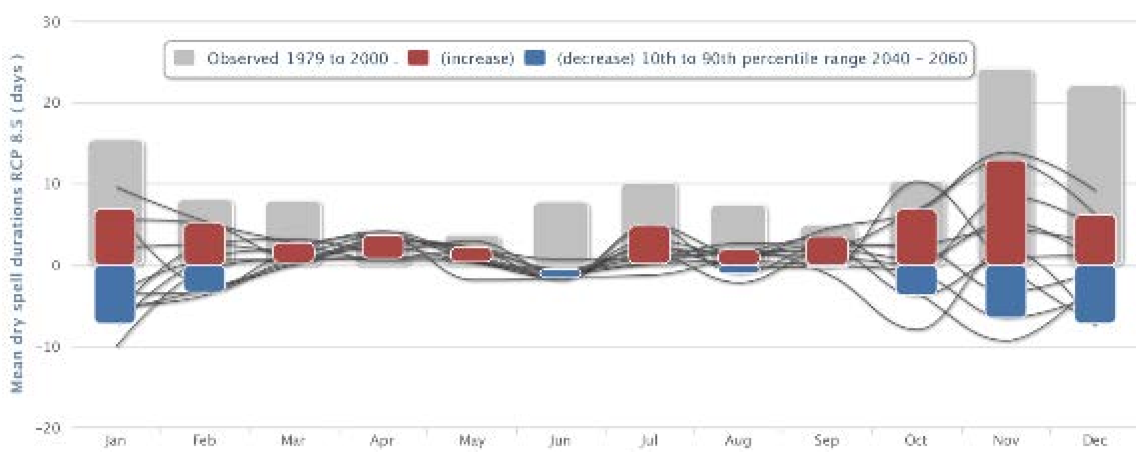



*Figure 17. Historical (1979-2000) and projected (2040-2060) change in mean dry spell duration. Projections represent the 10th to 90th percentile projections for 10 statistically downscaled CMIP5 GCMs for RCP 8.5. Source: Climate Information Platform.*

Similarly, there is uncertainty in the projected sign of change in drought conditions, though changes are projected to be minimal. The standardized precipitation evaporation index (SPEI), which is based on the difference between precipitation and potential evaporation, is projected to change by -0.6 to 0.1 by mid-

[45] Ranges represent ensemble averages for RCP 4.5 and RCP 8.5 for 2040-2059 relative to the historical period 1986-2015. Source: KNMI Climate Explorer.
[46] Based on the median projection of 10 models under RCP 8.5. Source: Climate Information Platform.

century.[47] Severe drought is projected to undergo no change or decline very slightly, with SPEI increasing by 0.0 to 0.2 by mid-century.[48] These changes are relatively minimal given that the SPEI extremes are ±2.33 per the Global Drought Monitor.

Due to projected temperature rise, potential evapotranspiration in the Volta Basin is projected to increase. However, if rainfall declines, actual evapotranspiration may be reduced.[49]

### SEA LEVEL RISE AND STORM SURGE

From 1925 to 2012, sea level at Ghana's port of Takoradi rose at an average rate of 2.2 mm per year (seen in Figure 18).[50] However, it is important to note that this trend is based on data taken from 1925 to 1965 and during intermittent periods between 2007 and 2012. Though there was a tide gauge installed from 1970 to 1996, the data is unreliable due to aging and a technical problem with the tide gauge.[51] More recent tide gauges have been installed, however they only provide data over one to five year periods, making it difficult to estimate sea level rise trends post-1970.[52,53]

In addition to rising sea levels, Ghana has already begun to experience increased tide-related waves, storm surge, extreme rainfall, increased coastal erosion and recession, and associated flooding.[54,55] Currently, local mean sea level is augmented by storm surge and tide-related waves by 2 to 6 m on an annual basis,[56] and coastal erosion ranges from 4 to 12 m per year[57]. Since the early 2000s, inundation due to these hazards has occurred annually.[58]

[47] Range represents the minimum 25th percentile to the maximum 75th percentile value for RCP 4.5 and RCP 8.5 ensembles. Projections reflect changes between the periods 1986-2005 and 2040-2059. Source: CCKP
[48] Range represents the minimum 25th percentile to the maximum 75th percentile value for RCP 4.5 and RCP 8.5 ensembles. Projections reflect changes between the periods 1986-2005 and 2040-2059. Source: CCKP
[49] McCartney, M., Forkuor, G., Sood, A., Amisigo, B., Hattermann, F., and Muthuwatta, L. 2012. The Water Resource Implications of Changing Climate in the Volta River Basin. Colombo, Sri Lanka: International Water Management Institute (IWMI). IWMI Research Report 146.
[50] NOAA. 2017. Mean Sea Level Trends: 410-001 Takoradi, Ghana. National Oceanic and Atmospheric Administration (NOAA). https://tidesandcurrents.noaa.gov/sltrends/sltrends_global_station.htm?stnid=410-001
[51] Boateng, I., Wiafe, G., & Jayson-Quashigah, P. N. (2017). Mapping vulnerability and risk of Ghana's coastline to sea level rise. Marine Geodesy, 40(1), 23-39.
[52] Caldwell, P. C., Merrfield, M. A., and Thompson, P. R.. 2015. Sea Level Measured by Tide Gauges from Global Oceans–The Joint Archive for Sea Level Holdings (NCEI Accession 0019568), Version 5.5, NOAA National Centers for Environmental Information, Dataset, doi:10.7289/V5V40S7W.
[53] Boateng et al. 2017
[54] Boateng et al. 2017
[55] Boateng, I. 2012. An assessment of the physical impacts of sea-level rise and coastal adaptation: a case study of the eastern coast of Ghana. Climatic Change, 114(2), 273-293.
[56] Boateng 2012
[57] World Bank 2010
[58] Boateng 2012

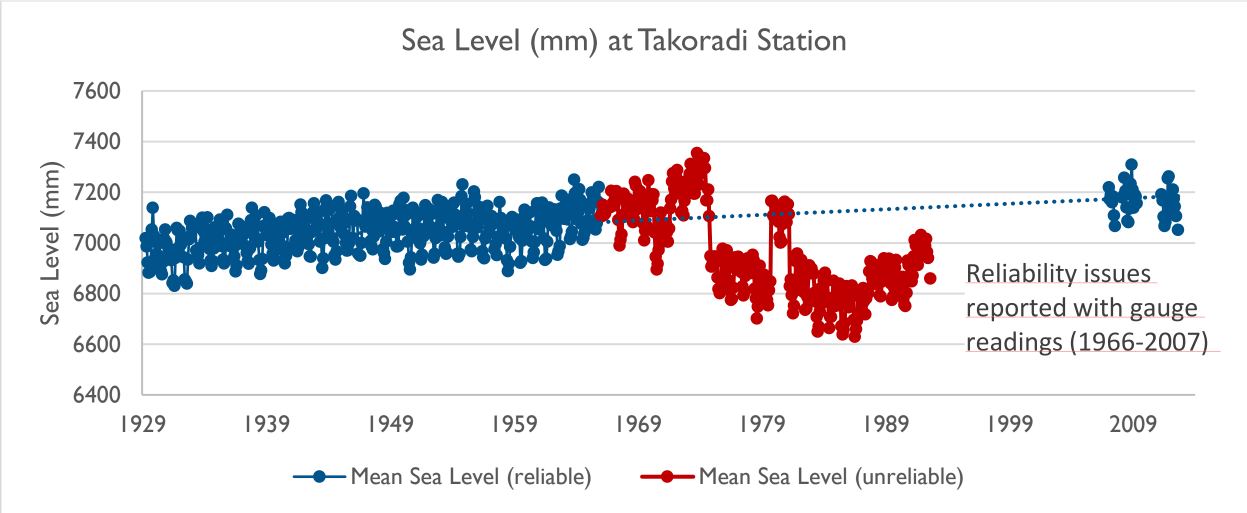



*Figure 18. Sea level record from Takoradi Port, Ghana. The trend line is depicted by the light blue dashed line. Source: NOAA 2017.*

Throughout this century, sea level is expected to continue to rise, reaching 0.4 to 0.7 m by the end of the century (2081-2100) relative to the 1986-2005 historical period. [59] Additionally, the frequency and intensity of tide-related waves and storm surge is expected to increase.[60] Sea level rise and increased tides and storm surge is expected to exacerbate shoreline erosion, recession, and inundation.[61, 62] Sea level rise magnifies erosion both by changing hydro-dynamic and morphologic conditions and processes.[63] Sea level rise impacts tidal hydrodynamics by increasing tidal ranges, consequently increasing tidal current velocities, which can exacerbate erosion.[64] Along sandy shorelines and coastal marshes, sea level rise alters coastal morphology by changing littoral zone processes that cause sand to be removed from the shore and deposited elsewhere (generally offshore), and by causing marsh migration and loss.[65] By 2040, land loss due to submergence is expected to reach 2.59 to 3.09 km$^2$ per year and erosion is projected to reach 0.15 to 0.68 km$^2$ per year.[66] Future intensification of these coastal hazards are likely to be especially problematic due to the low-lying nature of Ghana's coast, as depicted in Figure 19, below.

[59] Range reflects ensemble means of RCP 4.5 and RCP 8.5. Source: Figure 13.20 in Church et al. 2013
[60] Boateng et al. 2017
[61] World Bank 2010
[62] Boateng 2012
[63] Passeri, D. L., Hagen, S. C., Medeiros, S. C., Bilskie, M. V., Alizad, K., & Wang, D. 2015. The dynamic effects of sea level rise on low‐gradient coastal landscapes: A review. Earth's Future, 3(6), 159-181.
[64] Passeri et al. 2015
[65] Passeri et al. 2015
[66] World Bank 2010

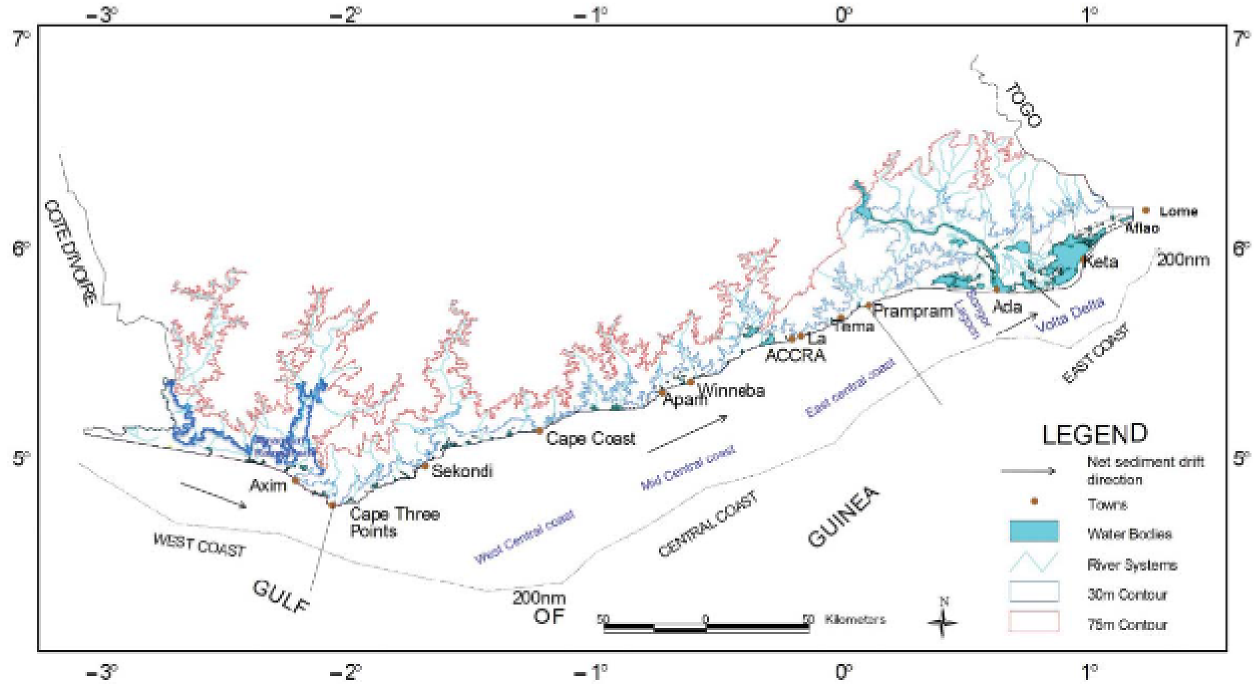



*Figure 19. Ghana's coastal area, including a 30 m contour (blue) and a 75 m contour (red). Source: Boateng et al. 2017*

# CLIMATE RISKS TO GHANA'S POWER SECTOR

The variation in climate conditions and the location of power sector assets and consumers mean that the implications of climate change on Ghana's power sector vary by zone. Climate change stressors can result in both direct and indirect impacts to power services and infrastructure. Direct impacts are characterized by climate stressors directly affecting the power system infrastructure, electricity generation, or transmission and distribution efficiency, or demand; while indirect impacts typically are those that are "facilitated" by climate stressors, for example increased reservoir sedimentation due to soil erosion from intense precipitation on degraded watersheds.

The impacts to the power sector vary by location, climate stressor, and power system component. For instance, coastal areas experience impacts from sea level rise and increasing tide-related waves and storm surge heights, while inland areas experience greater impacts from more intense increase in temperatures and associated dryness and wildfires. In some cases, issues arise gradually with increases in stressors, and in others they only arise once a threshold is exceeded.

This section considers a variety of potential climate impacts, broken down by risks to electricity generation, transmission and distribution, and demand.

## RISKS TO GENERATION

Ghana primarily relies on hydropower and thermal resources for electricity. Ghana has 3,327 MW of available capacity, 41 percent of which is hydropower, 58 percent thermal, and 1 percent solar.[67] Ghana's power plants are depicted in Figure 20, right. By 2030, Ghana's available capacity is expected to increase by 110 percent to nearly 7,000 MW, where 20 percent is expected to be hydropower, 60 percent thermal, and 20 percent renewables (primarily solar).

Ghana's generation resources have already begun to experience impacts from climate change, specifically impacts due to highly variable rainfall.[68]

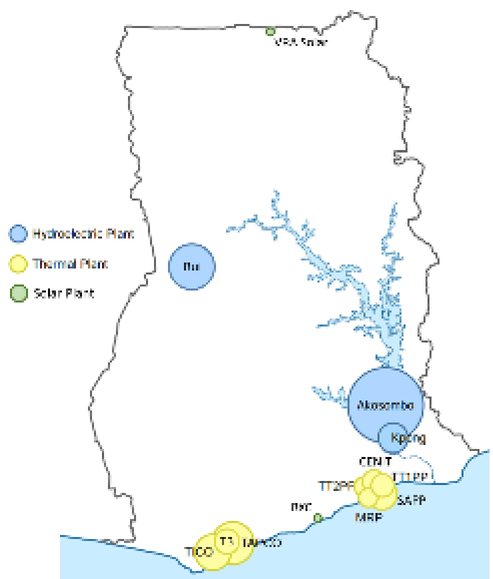



*Figure 20. Ghana generation plants, where circle size is proportional to capacity. Source: Modified from Power Systems Energy Consulting (PSEC) and Ghana Grid Company Limited (GRIDCo) 2010 Ghana Wholesale Power Reliability Assessment.*

[67] Ghana Energy Commission, 2015. 2015 Energy (Supply and Demand) Outlook for Ghana.
[68] World Bank 2010

## HYDROPOWER

Ghana relies heavily on hydropower, with three plants composing 41 percent of Ghana's available electric capacity, as shown in Table 2 (below) and as red circles in Figure 21 (right). All of these are within the Volta Basin,[69] which covers 64 percent of the country.[70] By 2030, an additional small hydropower plant (31 MW) is planned in the North region. Due to an anticipated increase in thermal and renewable resources, hydropower is expected to make up only 20 percent of available capacity in 2030. Potential small to medium scale hydropower sites (10-100 MW) have been identified for future use, including eight plants composing 667 MW in the Volta Basin and eight plants composing 308 MW in the Southwestern Basin, depicted by blue triangles in Figure 21.


*Figure 21. Existing (red circles) and potential (blue triangles) hydropower in the Volta Basin (including the Black Volta, Red and White Volta, and Oti sub-basins), the Southwestern Basin, and the Coastal Basin. Source: USAID IRRP Whitepaper on Renewable Energy Potential in Ghana*

Since the largest of the dams, Akosombo, was built in the 1960's, Ghana has heavily depended on it for power generation. Because hydropower energy production is strongly impacted by annual precipitation, as illustrated in Figure 22 (right), a heavy reliance on hydropower left Ghana vulnerable to impacts of precipitation reductions. Hydrologic drought in the Volta Basin has led to severe power rationing during several years, including 1983, 1997, 2006, and 2007. The 2006/2007 event was the most severe. During this event, the Volta Basin experienced reduced rainfalls, leading to low water levels in the Akosombo and Kpong Dams, requiring power rationing. The rationing limited the output of all economic sectors, and reduced Ghana's economic growth from 6.5 percent to 4 - 5 percent. Companies spent an estimated $62 million USD per month on supplemental power generation, and the shortage reduced Internal Revenue Service revenue by $14 million USD.[71]

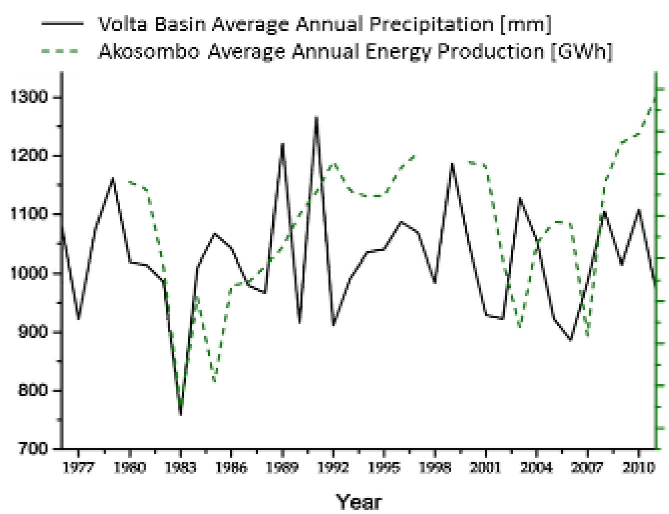



*Figure 22. Historical Volta Basin precipitation and Akosombo energy production. Source: Modified from Kabo-Bah et al. 2016*

[69] ICF. 2017. IRRP Progress, Outlook, and Draft Modeling Results. USAID IRRP Project. April 20, 2017.
[70] FAO. The Volta Basin. http://www.fao.org/docrep/W4347E/w4347e0u.htm
[71] Bekoe, E. O., & Logah, F. Y. 2013. The impact of droughts and climate change on electricity generation in Ghana. Environmental Sciences, 1(1), 13-14.

| TABLE 2. EXISTING (2017) HYDROPOWER PLANTS | | | |
|---|---|---|---|
| REGION | PLANT NAME | AVAILABLE CAPACITY [MW] | SHARE OF GHANA'S TOTAL CAPACITY [%] |
| North | Bui | 330 | 10% |
| Southeast | Akosombo | 900 | 27% |
| | Kpong | 140 | 4% |
| **TOTAL** | | **1,370** | **41%** |

Due to significant seasonal and annual variability in rainfall, Ghana suffers impacts from floods in addition to drought. For instance, during the fall of 2007, following severe drought-induced power shortages, Ghana experienced severe flooding due to extreme rainfall. Hundreds of thousands of people were displaced, especially in the north, costing millions of dollars including for resettlement and rehabilitation.[72]

Using one representative climate model and one emissions scenario,[73] McCartney et al. (2012) found that by mid-century, the Volta Basin's average annual rainfall, mean annual runoff, and mean groundwater recharge are projected to decline, reducing water availability for hydropower generation. More specifically, the authors estimate that by 2050, just 52 percent of potential hydroelectricity will be generated, with the amount declining through the end of the century. In contrast, Obahoundje et al. (2017) found that future changes in runoff and hydropower production are uncertain, varying by climate change and land cover change scenarios.[74] In this study, Bui power production is expected to increase the most under a land cover change and wet climate scenario (+41%), and decrease the most under a no land cover change and dry climate scenario (-54%).

Though water availability projections are uncertain, there is a consensus within the literature that if the impacts of climate change on water resources are not managed, Ghana's hydropower generation will be negatively impacted.

The following section details climate risks by stressor.

[72] Bekoe and Logah 2013
[73] The authors used the A1B emissions scenario, while considered to be a more moderate scenario as emissions peak around mid century before declining at centurys end, it is a high emissions scenario up to mid-century
[74] Obahoundje, S., Ofosu, E.A., Akpoti, K. and Kabo-bah, A.T., 2017. Land Use and Land Cover Changes under Climate Uncertainty: Modelling the Impacts on Hydropower Production in Western Africa. Hydrology, 4(1), p.2. Authors assume a 1°C temperature increase

## TABLE 3. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO HYDROPOWER IN GHANA [75]

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON HYDROPOWER | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Temperature increases and extremes | Average, minimum, and maximum temperatures are projected to increase in all zones, increasing water temperature and potential evaporation and transpiration rates. All models project increases in average annual temperature. By mid-century, the North is projected to experience a 1.3 to 1.8°c increase, while the other zones are projected to experience a 1.2 to 1.6°c increase.[76] By 2035, the Volta Basin is projected to experience a 1.0°c increase.[77] Agricultural irrigation demand is projected to increase by 4.2 to 8.4 percent by 2030.[78] | **Impacts on Conventional Storage and Run-of River.**<br>Increased temperatures can lead to increased demand by competing water users (e.g., irrigators) reducing water available for generation.<br>**Impacts on Conventional Storage.**<br>Increased potential evaporation and transpiration reduces water available for generation.<br>Higher water temperatures can reduce dissolved oxygen levels and affect biological processes for aquatic species.<br>**Impacts on Run-of-River.**<br>Increased water temperatures lead to increased temperatures in the river reach where water is diverted. | Since hydropower is concentrated in the Volta River Basin, the risks to hydropower are highest there. Agricultural water consumption is projected to increase as a result of higher temperatures. The Southwest region doesn't contain any hydropower resources, though there is potential for smaller scale hydropower development. |

[75] Based on the following sources (a) Ebinger, J. and Vergara, W. 2011. Climate Impacts on Energy System: Key Issues for Energy Sector Adaptation. Energy Sector Management Assistance Program (ESMAP) and World Bank; (b) Hammer, S. A., J. Keirstead, S. Dhakal, J. Mitchell, M. Colley, R. Connell, R. Gonzalez, M. Herve-Mignucci, L. Parshall, N. Schulz, M. Hyams. 2011. Climate Change and Urban Energy Systems. Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network, C. Rosenzweig, W. D. Solecki, S. A. Hammer, S. Mehrotra, Eds., Cambridge University Press, Cambridge, UK, 85–111.; (c) Seattle City Light. 2013. Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan; (d) U.S. Agency for International Development (USAID). 2012. Energy Systems: Addressing Climate Change Impacts on Infrastructure: Preparing for Change; (e) U.S. Department of Energy (DOE). 2016. Climate Change and the Electricity Sector: Guide for Assessing Vulnerabilities and Developing Resilience Solutions to Sea Level Rise; (f) Western Electricity Coordinating Council (WECC). 2014. Assessment of Climate Change Risks to Energy Reliability in the WECC Region.

[76] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.

[77] Based on results from the CCLM model for the A1B scenario for 2021-2050 relative to 1983-2012. Source: McCartney et al. 2012.

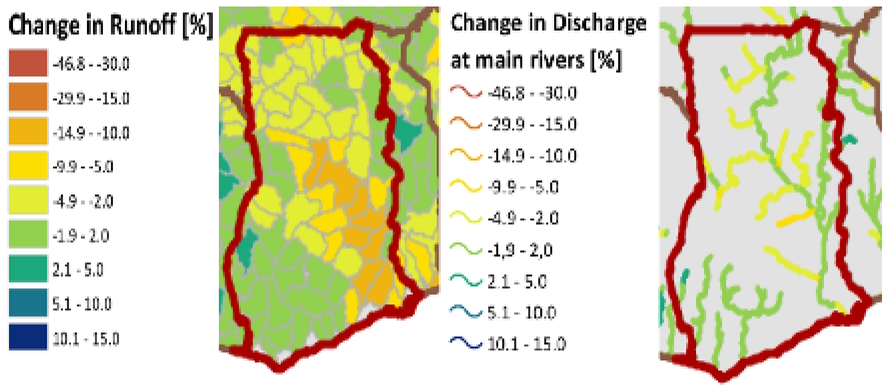
[78] Projections based on AquaCrop model for wet and dry scenarios for the country and the globe. Source: Amisigo et al. 2015.

## TABLE 3. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO HYDROPOWER IN GHANA [75]

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON HYDROPOWER | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Extreme precipitation events | There is strong model agreement of projected increases in the proportion of precipitation that falls during extreme rainfall events, increasing high flows and the frequency and intensity of flooding. By mid-century, the proportion of precipitation falling during extreme rainfall (99th percentile) events is projected to increase the most in the North (24 to 26 percent) and slightly less in the other three zones (18 to 25 percent).[79] | **Impacts on Conventional Storage and Run-of River.**<br>Extreme precipitation is expected to directly damage infrastructure and damage access roads, causing service disruptions, higher repair costs, and inhibiting access to plants.<br>Extreme precipitation increases risk of cavitation damage to turbines from plant operation at higher-than-optimal loads.<br>Depending upon reservoir capacity and design, extreme precipitation can replenish reservoirs and increase generation, or result in excess spillage.<br>Increased precipitation intensity can increase sedimentation and siltation, reducing dam and reservoir capacity in storage systems and reduce weir or holding pond storage capacity in run-of-river systems.<br>Increased sedimentation increases potential for turbine damage and associated increases in maintenance costs.<br>Undesired spillage is likely to increase due to increased extreme precipitation and associated high-flow periods. The Bagre Dam (located in Burkina Faso along the White Volta near the Ghana border) already opens its gates on annual basis to avoid excess water accumulation and damage to the dam banks,[80] and in the past has had to do so during torrential rains, leading to significant flooding of the downstream communities in Ghana[81]. | Increases in extreme rainfall events pose risks to existing hydropower infrastructure in the Volta River Basin. The risks are localized (e.g., direct erosion and damages), but also could increase as runoff moves downstream from North to Southeast.<br>The North is projected to undergo slightly greater increases in extreme precipitation than the Southeast, however the North has only one existing and one planned hydropower plant while the Southeast contains the vast majority of the hydropower capacity. Notably, the Bui hydropower plant in the North was designed based on the probable maximum flood (PMF).[82] However, because the PMF estimate did not consider climate change, the plant may not be protected against potential increases in PMF due to projected increases in intensity of extreme rainfall events. |

[79] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[80] Ghana Web. 2013. Bagre Dam spillage begins today. http://www.ghanaweb.com/GhanaHomePage/NewsArchive/Bagre-Dam-spillage-begins-today-286657; Jalulah, W. N. 2015. Bagre Dam Spillage Floods Farmlands in U/East Region. http://thechronicle.com.gh/bagre-dam-spillage-floods-farmlands-in-ueast-region-as-nadmo-begins-assessment-in-3-districts/
[81] Asumadu-Sarkodie, S., Owusu, P.A. and Rufangura, P. 2015. Impact analysis of flood in Accra, Ghana. Advances in Applied Science Research.
[82] Mortey, E.M., Ofosu, E.A., Kolodko, D.V. and Kabobah, A.T. 2017. Sustainability Assessment of the Bui Hydropower System. Environments, 4(2), p.25.

**TABLE 3. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO HYDROPOWER IN GHANA [75]**

<table>
<tr><th>CLIMATE STRESSOR</th><th>CHANGE IN CONDITION</th><th>IMPACTS ON HYDROPOWER</th><th>IMPLICATIONS FOR GHANA</th></tr>
<tr>
<td><br>Water Flow, Volume, and Timing</td>
<td>Future water flow, volume, and timing are uncertain as models differ on the sign of change, projecting approximately a ±10% change in discharge in the Volta Basin by mid-century, as illustrated in Figure 23, right.[83] Flow is largely determined by precipitation, which is likely to shift, with more occurring between latter part of the rainy season and early part of the dry season (+3 to 5 percent), and less occurring during the early part of the rainy season (-2 percent) by mid-century. This may present a challenge, as temperature peaks in the dry season (February to April) and is projected to increase the most during this period, which may result in increased cooling demand, thereby increasing hydropower needs during these months.</td>
<td>Impacts on Conventional Storage.<br><br>Generation potential is likely to increase later in the year, and decrease during the early part of the rainy season, due to the shifting rainfall patterns.<br><br>Impacts on Run-of-River.<br><br>During periods of decreased rainfall, increases in the frequency and duration of minimum design flows could reduce generation reliability.<br><br><br><br>Figure 23. Projected change in runoff (left) and discharge (right) by mid-century. Source: Poyry and ECOWAS ECREE 2017</td>
<td>Annual mean flows have historically been lower in the northern Volta sub-basins (the Black Volta, White Volta, and Oti have an average flow of 233 $m^3/s$) than the southern sub-basins (the Main Volta and Lower Volta have an average flow of 850 $m^3/s$) and all of these sub-basins are projected to undergo a similar (2 to 4 percent) decrease in annual flow.[84]<br><br>Based on projected precipitation shifts, hydropower production may increase slightly between latter part of the rainy season and early part of the dry season and decrease slightly early part of the rainy season throughout the country.</td>
</tr>
</table>

[83] Poyry and ECOWAS ECREE 2017. Projections are for 20-year period centered around 2055 relative to 16-year period centered around 2006. Values are the median of 30 climate model runs from 15 regional climate models under RCP 4.5 and RCP 8.5 emission scenarios.
[84] Amisigo et al. 2015. Projected change in flow based on average of Ghana dry and wet and Global dry and wet scenario projections.

## TABLE 3. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO HYDROPOWER IN GHANA [75]

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON HYDROPOWER | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Dry spells & drought | Projections for annual precipitation and consecutive dry days are mixed in sign. By mid-century, the model ensemble averages project a 1 to 2 percent increase in annual precipitation for all zones, and a -0.7 to 0.7 percent change in consecutive dry days in the North and a 0.8 to 1.1 percent increase in consecutive dry days in all other zones. Soil moisture content is projected to increase throughout the year, with annual average soil moisture content increasing by 2 percent in the North and 2 to 4 percent in the other zones, with the greatest increases coinciding with projected precipitation increases (October to December in the North and November to January in the other zones).[85] Additionally, drought is projected to become more frequent and intense.[86] | **Impacts on Conventional Storage.**<br>During periods of decreased precipitation and increased consecutive dry days, there may be a decrease in stored water and increase in water requirements and consumption of competing water users, reducing generation.<br>**Impacts on Run-of-River.**<br>During periods of decreased precipitation and increased consecutive dry days, there is a potential for severe power generation reductions due to the lack of storage buffer, and an increase in water competition further reducing water availability. | Hydrologic drought has negatively impacted Ghana's hydropower production in recent years. As drought events are projected to become more frequent and intense, so are the impacts.[87] The North has historically been drier than the rest though it is not expected to experience a change in consecutive dry days and has only one existing hydropower plant and one planned small hydropower plant. The Southeast has historically been slightly cooler and wetter and is projected to undergo a slightly lower temperature increase, but contains over three quarters of Ghana's available hydropower capacity and nearly one third of the country's total available capacity. Additionally, should drought increase water requirements upstream, water availability may decrease downstream. |
| Sea level rise | Throughout this century, sea level is expected to continue to rise, reaching 0.4 to 0.7 m by 2090 relative to the 1986-2005 historical period.[88] Additionally, the frequency and intensity of tide-related waves and storm surge is expected to increase, exacerbating exacerbate shoreline erosion, recession, and inundation.[89] By 2040, land loss due to submergence is expected to reach 2.59 to 3.09 $km^2$ per year and erosion is projected to reach 0.15 to 0.68 $km^2$ per year.[90] | **Impacts on Conventional Storage and Run-of River.**<br>These coastal hazards may lead to inundation of and direct damage to low-lying infrastructure and access roads.<br>**Impacts on Conventional Storage.**<br>The combination of reduced downstream flow and sedimentation from upstream impoundment can result in increased salinity and land subsidence. | Ghana's hydropower plants may not experience significant impacts from sea level rise and other coastal hazards as all existing and planned plants are inland as opposed to along the coast. However, the impact of upstream impoundment effects coastal erosion and water quality in the Volta Estuary due in part to changes in the river flows, increased sea-level rise, and removal of mangroves for wood. |

85 Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
86 Kankam-Yeboah, K., Amisigo, B., & Obuobi, E. (2011). Climate change impacts on water resources in Ghana.
87 Bekoe and Logah 2013; Kankam-Yeboah et al. 2011
88 Range reflects ensemble means of RCP 4.5 and RCP 8.5. Source: Figure 13.20 in Church et al. 2013
89 Boateng et al. 2017 and Boateng 2012
90 World Bank 2010

## THERMAL

Power shortages due to a heavy dependence on hydropower has led Ghana to view the development of thermal generation as an energy security necessity.[91] Currently, thermal generation composes 58 percent of Ghana's available capacity (Table 4). By 2030, thermal generation capacity is expected to increase by 115 percent and compose 60 percent of available capacity (Table 5).[92]

All of Ghana's existing thermal power plants are along the coast, putting them at risk of inundation from sea level rise and increased tide-related waves, storm surge, and erosion. Coastal hazards and other climate risks are explored in the following section.[93]

**TABLE 4. EXISTING (2017) THERMAL GENERATION PLANTS**

| REGION | FUEL TYPE | PLANT NAME | AVAILABLE CAPACITY [MW] | SHARE OF GHANA'S TOTAL CAPACITY [%] |
|---|---|---|---|---|
| ASHANTI | OIL | TROJAN 2A | 16 | 0% |
| SOUTH-EAST | GAS | SAPPL | 180 | 5% |
| | GAS | TT2PP | 45 | 1% |
| | OIL | TROJAN 28 | 16 | 0% |
| | OIL/GAS | KARPOWERSHIP 1 | 247 | 7% |
| | OIL/GAS | TT PP | 100 | 3% |
| | OIL/GAS | KTPP | 200 | 6% |
| | OIL/GAS | MRP | 70 | 2% |
| | OIL/GAS | TROJAN1 | 25 | 1% |
| | OIL | CENIT | 100 | 3% |
| SOUTH-WEST | GAS | AMERI_ 2016 | 230 | 7% |
| | OIL | GP TARKWA PLANT | 33 | 1% |
| | OIL | GP CHIRANO PLANT | 30 | 1% |
| | OIL | GP DARMANG PLANT | 20 | 1% |
| | OIL/GAS | TAPCO (TL) | 305 | 9% |
| | OIL/GAS | TICO (T2) | 320 | 10% |
| **TOTAL** | | | **1,937** | **58%** |

[91] World Bank 2010
[92] ICF. IRRP Progress, Outlook, and Draft Modeling Results. USAID IRRP Project. April 20, 2017.
[93] Based on the following sources: Ebinger and Vergara 2011, Hammer et al. 2011, Seattle City Light 2013, USAID 2012, and U.S. DOE 2016, and WECC 2014

| TABLE 5. PLANNED (2030) THERMAL GENERATION PLANTS | | | | |
|---|---|---|---|---|
| REGION | FUEL TYPE | PLANT NAME | AVAILABLE CAPACITY [MW] | SHARE OF GHANA'S TOTAL CAPACITY [%] |
| ASHANTI | OIL/GAS | ASHA COMBINED CYCLE | 48 | 1% |
| NORTH | OIL/GAS | NORT COMBINED CYCLE | 335 | 5% |
| SOUTH-EAST | GAS | TT2PP | 45 | 1% |
| | GAS | SAPPL | 180 | 3% |
| | OIL/GAS | SOUT COMBUSTION TURSI 1 | 50 | 1% |
| | OIL/GAS | MRP | 70 | 1% |
| | OIL/GAS | TT PP | 100 | 1% |
| | OIL/GAS | KTPP | 200 | 3% |
| | OIL/GAS | CENPOWER | 340 | 5% |
| | OIL/GAS | SAPP 2 | 370 | 5% |
| | OIL/GAS | EARLY POWER | 378 | 5% |
| | OIL | CENIT | 100 | 1% |
| SOUTH-WEST | GAS | AMERI_2021 | 230 | 3% |
| | OIL | GP DARMANG PLANT | 20 | 0% |
| | OIL | GP CHIRANO PLANT | 30 | 0% |
| | OIL | GP TARKWA PLANT | 33 | 0% |
| | OIL/GAS | AMANDI | 190 | 3% |
| | OIL/GAS | TICO (T2) | 320 | 5% |
| | OIL/GAS | SOUT COMBUSTION TURSI 2 | 432 | 6% |
| | OIL/GAS | SOUT COMBINED CYCLE | 699 | 10% |
| **TOTAL** | | | **4,170** | **60%** |

## TABLE 6. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO THERMAL GENERATION IN GHANA

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON THERMAL GENERATION | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Temperature increases and extremes | Average, minimum, and maximum temperatures are projected to increase in all zones, increasing water temperature and potential evaporation and transpiration rates. All models project increases in average annual temperature. By mid-century, the North is projected to experience a 1.3 to 1.8°c increase, while the other zones are projected to experience a 1.2 to 1.6°c increase.[94] | Warmer intake temperatures of cooling water reduce the thermal gradient and generation efficiency, increasing fuel costs to maintain output. For natural gas fired power plants, each 1°C increase above 15°C leads to capacity decreases of 0.3 to 0.5 percent[95] for wet cooling combined cycle, 0.7 percent for air-cooled combined cycle, and 1.0 percent for simple cycle.[96,97]<br><br>Increased temperatures can lead to increased demand by competing water users (e.g., irrigators) reducing water available for generation. | The North has historically experienced the highest temperatures and is projected to experience the greatest temperature increase. Currently, there are no thermal plants in the North, however there are plans to build a 335 MW combined cycle plant by 2030. Illustrative potential capacity decreases based on simple temperature-efficiency relationships from other studies are presented in Figure 24.[98] Based on changes in average annual temperature, these relationships indicate that by mid-century, capacity would decrease the least (0.4 to 0.5 percent) in combined cycle wet cooling plants in valley, coastal, and mountain areas of Ashanti, the Southeast, or the Southwest, and would decrease the most in simple cycle plants in the North (1.3 to 1.8 percent). |

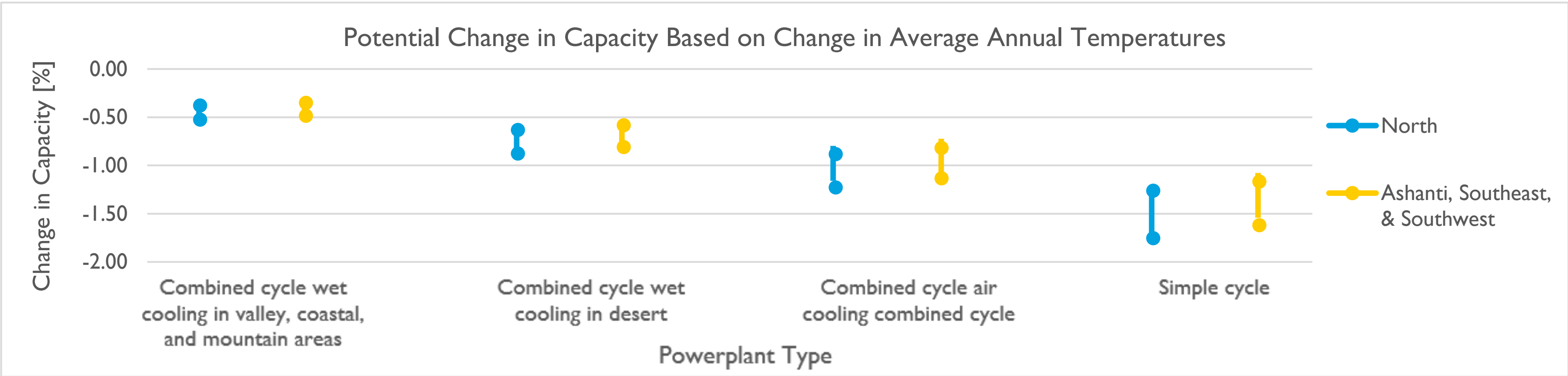



*Figure 24. Potential change in natural gas fired power plant capacity based on change in average annual temperature for the North and for Ashanti, the Southeast, and the Southwest regions. The upper bound represents the change in capacity associated with RCP 4.5 projections, while the lower bound represents change in capacity associated with RCP 8.5 projections. Capacity-temperature relationship based on Sathaye et al. 2013, Neumann and Price 2009, and Acclimatise 2009.*

[94] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[95] Valley, coastal, and mountain plants are closer to a 0.3 percent decrease and desert plants are closer to a 0.5 percent decrease.
[96] Based on a study of California power plants: Sathaye, J., Dale, L., Larsen, P., Fitts, G., Koy, K., Lewis, S., Pereira de Lucena, A. (2013). Estimating Impacts of Warming Temperatures on California's Electricity System. Global Environmental Change 23: 499-511. Similar values determined by Neumann, J. and J. Price. 2009. Adapting to Climate Change: The Public Policy Response: Public Infrastructure. Resources for the Future Climate Policy Program, and Acclimatise. (2009.) Carbon Disclosure Project Report: Global Electric Utilities. Building Business Resilience to Inevitable Climate Change series.
[97] Natural gas combined and simple cycle power plants are both used in Ghana. It is assumed that the California study findings are applicable to Ghana infrastructure.
[98] Capacity-temperature relationship based on Sathaye et al. 2013, Neumann and Price 2009, and Acclimatise 2009

**TABLE 6. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO THERMAL GENERATION IN GHANA**

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON THERMAL GENERATION | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Extreme precipitation events | There is strong model agreement of projected increases in the proportion of precipitation that falls during extreme rainfall events, increasing high flows and the frequency and intensity of flooding. By mid-century, the proportion of precipitation falling during extreme rainfall (99th percentile) events is projected to increase the most in the North (24 to 26 percent) and slightly less in the other three zones (18 to 25 percent).[99] | Extreme precipitation and associated flooding are expected to directly damage generation infrastructure and damage access roads, causing service disruptions, higher repair costs, and inhibiting access to plants. | Increases in extreme precipitation and associated flooding are likely to increase the severity of damages. These impacts will likely be most severe in areas that already experience severe flooding. Accra and the Sekondi-Takoradi Metropolis already experience severe flooding during heavy rainfall events,[100]and these areas contain the vast majority of existing power plants. Nearly all of Ghana's planned thermal plants are also within the low-lying coastal regions (91 percent), indicating that they will likely be highly exposed to extreme precipitation and flooding. As the plants are along the coast, sea level rise and storm surge may compound flood risk during extreme precipitation events, particularly if the areas have poor drainage systems. |
| Dry spells & drought | Projections for annual precipitation and consecutive dry days are mixed in sign. By mid-century, the model ensemble averages project a 1 to 2 percent increase in annual precipitation for all zones and a seasonal shift, with more occurring between latter part of the rainy season and early part of the dry season (+3 to 5 percent), and less occurring during the early rainy season (-2 percent). Consecutive dry days are projected to change by -0.7 to 0.7 percent in the North and increase by 0.8 to 1.1 percent in all other zones. Annual average soil moisture content is projected to increase by 2 percent in the North and 2 to 4 percent in the other zones, with the greatest increases coinciding with projected precipitation increases (October to December in the North and November to January in the other zones).[99] In Accra, mean dry spell duration is projected to increase slightly in most months.[101] | During periods of decreased precipitation and increased consecutive dry days, there may be a decrease in water supply and increase in water competition, reducing the availability of cooling water and therefore reducing the reliability of power plants. | While the North has historically been drier than the rest and is projected to experience a greater increase in average annual temperature, the Southeast and Southwest contain the vast majority of existing assets, and these areas are therefore most exposed and at risk. The planned 335 MW combined cycle plant in the North will also be at risk of experiencing adverse effects from dry spells and drought. |

[99] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[100] Kankam-Yeboah et al. 2011; Addo, I.Y. and Danso, S.Y. 2017. Sociocultural factors and perceptions associated with voluntary and permanent relocation of flood victims: A case study of Sekondi-Takoradi Metropolis in Ghana. Jàmbá: Journal of Disaster Risk Studies, 9(1), pp.1-10.
[101] Climate Information Portal

**TABLE 6. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO THERMAL GENERATION IN GHANA**

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON THERMAL GENERATION | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Sea level rise | Throughout this century, sea level is expected to continue to rise, by 3 mm per year,[102] reaching 0.15 m by 2050 relative to the 1986-2015 historical period. Additionally, the frequency and intensity of tide-related waves and storm surge is expected to increase, exacerbating shoreline erosion, recession, and inundation.[103,104,105] By 2040, land loss due to submergence is expected to reach 2.59 to 3.09 $km^2$ per year and erosion is projected to reach 0.15 to 0.68 $km^2$ per year.[106] | These coastal hazards may lead to inundation of and direct damage to low-lying generation infrastructure and access roads.<br><br>Increased saltwater intrusion and exposure may increase corrosion of electrical components. | These impacts will most likely be severe in the coastal Southeast and Southwest. Nearly all of Ghana's existing and planned thermal plants are within these regions (99 percent and 91 percent, respectively) and along the coast, indicating that they will likely be highly exposed to sea level rise, storm surge, and shoreline erosion. Flooding due to sea level rise and storm surge may be compounded by extreme precipitation events, particularly if the areas have poor drainage systems. |

[102] Boateng et al. 2017
[103] Boateng et al. 2017
[104] World Bank 2010
[105] Boateng 2012
[106] World Bank 2010

## RENEWABLES

In realizing the country's broader vision of developing an 'Energy Economy' which has the ability to sustainably produce, supply and distribute high quality energy services, one of the main goals in the Ghana Strategic National Energy Plan is to promote the development and utilization of renewable energy and energy efficiency technologies.[107] This is buttressed by the country's policy commitment to scale up of renewable energy penetration by 10 percent by 2030,[108] in effort to reduce GHG emissions. Renewables presently make up about 0.6 percent of the country's grid connected installed capacity; however, this is very likely to change in future years given the planned renewable energy projects, and increasing interest by investors and policy makers to promote renewable projects.

**Wind** potential exists in multiple areas in Ghana with estimated wind power class ranging from Class III to V.[109] However, the southeastern coastal areas of the country, which have appreciable wind potential (wind power Class III), have been an area of much attention for investors. This is partly due to a ground-based wind resource assessment that seems to indicate high resource availability along the coast, as per the Energy Commission. Another reason is the proximity to transmission and transport infrastructure that could enhance project development. The estimated total technical wind potential in the country is in excess of 5000 MW.[110]

There are presently no commercial scale wind farms in the country. However, there has been investor interest with over one GW of provisional licenses given out over the past three years.[111]

**Solar** Ghana has significant solar potential with an estimated annual sunshine duration between 1500–3000 hours and 4.5–6 kilowatt-hours per square meter per day[112] of solar irradiation. The northern part of the country has relatively higher radiation levels. Solar photovoltaic is presently the most suitable solar technology due to the higher percentage of diffuse radiation in the recorded global irradiance.

There are currently two utility scale solar PV plants (with a total installed capacity of 22.5 MWp) connected to the medium voltage distribution system in the country. A 2.5 MWp solar plant is located in Navrongo in the Upper East region and a 20 MWp is located in Winneba in the Central region of Ghana. Their aggregated annual energy generation is about 36 GWh.

**Biomass** There is a large potential for Ghana to use biomass for electricity generation due to the widely available feedstock materials from residues resulting from the various stages of agricultural and forestry activities which includes for example crop harvesting residues, wood logging residues, wood processing residues, agro processing residues, and residue

[107] Ghana Energy Commission. 2006. Strategic National Energy Plan 2006-2020,
[108] Ghana. 2015. Intended nationally determined contribution and explanatory note.
[109] NREL. SWERA. https://maps.nrel.gov/swera
[110] IRENA. 2015. Ghana Renewable Readiness Assessment.
[111] Ghana Energy Commission. Register of Licenses. http://www.energycom.gov.gh/licensing/register-of-licenses
[112] Ghana Energy Commission. 2015. Renewable Energy Policy Review, Identification of Gaps and Solutions in Ghana.

from farm animals.  Although there are no grid connected biomass generation plants, some agro-processing companies in the country have small onsite generations plants which utilize their residues as feedstock to generate electricity for local consumption.

**Municipal Waste-to-Energy** is an identified source of renewable energy in the country as indicated in the energy sector strategic plan.[113] Kumasi and Accra, including their respective suburbs and surroundings have been identified to produce a total of about 4,100 tons daily[110] of municipal solid waste. This is a potential source of bioenergy for power production. There is presently a 100kW waste-to-energy plant in the Greater Accra region, connected to the distribution grid in Accra. The plant has the capacity to process about 25 tons of waste daily.

Table 7, below, lists renewables generation plants that are planned for installation by 2030.

**TABLE 7. PLANNED (2030) RENEWABLE GENERATION PLANTS**

| REGION | FUEL TYPE | PLANT NAME | AVAILABLE CAPACITY [MW] | SHARE OF GHANA'S TOTAL CAPACITY [%] |
|---|---|---|---|---|
| ASHANTI | BIOMASS | ASHA BIOGAS | 4 | 0.1% |
| | SOLAR PV | ASHA SOLAR PV 1-3 | 140 | 2.0% |
| NORTH | BIOMASS | NORT BIOGAS | 7 | 0.1% |
| | SOLAR PV | NORT SOLAR PV 1-3 | 387 | 5.5% |
| | SOLAR PV | RA SOLAR | 2 | 0.0% |
| SOUTH-EAST | BIOMASS | SOUT BIOGAS | 7 | 0.1% |
| | SOLAR PV | BXCSOLAR | 18 | 0.3% |
| | SOLAR PV | OUT SOLAR PV | 100 | 1.4% |
| | SOLAR PV | SOUT SOLAR PV 1-4 | 185 | 2.6% |
| | WIND | SOUT WIND TURBINE | 300 | 4.3% |
| SOUTH-WEST | BIOMASS | OUT BIOGAS | 8 | 0.1% |
| | SOLAR PV | SOUT SOLAR PV 5-8 | 270 | 3.9% |
| **TOTAL** | | | **1428** | **20%** |

While Ghana has historically relied very little on renewable sources, there are indications that renewables would be vulnerable to current and future climate conditions. Ghana's agricultural sector is predominantly rain-fed and has historically been negatively impacted by drought, particularly in the

[113] Ghana Energy Commission 2006

northern parts of the country, indicating that biomass is vulnerable to potential decreases in precipitation and dry spells.[114,115] Crops grown along the coast have already been negatively impacted by sea water intrusion as they depend heavily on groundwater for irrigation.[116] Solar PV and wind, which are already subject to supply intermittency, may become less reliable due to the possible changes in solar irradiance, air temperature, and weather patterns.

The following section describes potential climate risks to renewable generation in Ghana. [117]

[114] Integrated Drought Management Programme (IDMP). 2016. Drought conditions and management strategies in Ghana. http://www.droughtmanagement.info/wp-content/uploads/2016/10/WS6-Ghana.pdf
[115] Amisigo et al. 2015
[116] Integrated Drought Management Programme (IDMP). 2016. Drought conditions and management strategies in Ghana. http://www.droughtmanagement.info/wp-content/uploads/2016/10/WS6-Ghana.pdf
[117] Based on the following sources: Ebinger and Vergara 2011, Hammer et al. 2011, Seattle City Light 2013, USAID 2012, and U.S. DOE 2016, and WECC 2014

## TABLE 8. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO RENEWABLES IN GHANA

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON RENEWABLES | IMPLICATIONS FOR GHANA |
|---|---|---|---|
|  Temperature increases and extremes | Average, minimum, and maximum temperatures are projected to increase in all zones. All models project increases in average annual temperature. By mid-century, the North is projected to experience a 1.3 to 1.8°c increase, while the other zones are projected to experience a 1.2 to 1.6°c increase.[118] Additionally, solar radiation is projected to decrease in Ghana by 0.21 W/m$^2$/year through 2100.[119] | Increased temperatures lower solar photovoltaic (PV) efficiency and energy output. Output is typically rated at 25°C and decreases by 0.25 percent (amorphous) to 0.5 percent (crystalline) per 1°C rise.[120,121]<br>Based on projected changes in irradiance and temperature in Ghana, solar PV power output is projected to decrease over time for mono-crystalline cells.[122]<br>Increased air temperature lowers wind power; specifically a 1°C increase in temperature lowers air density and wind power by approximately 0.33 percent.[123] | Illustrative potential capacity decreases based on simple temperature-efficiency relationships are presented in Figure 25. Based on changes in average annual temperature, these relationships indicate that by mid-century, capacity would decrease the least (0.3 to 0.4 percent) for amorphous solar PV in Ashanti, the Southeast, and the Southwest and decrease the most (0.6 to 0.9 percent) for crystalline solar PV in the North. Similar values are estimated for change in solar PV mono-crystalline cell power output as a function of change in temperature and irradiance, with output estimated to decrease by 0.2% by 2050 relative to 2006.[124] |

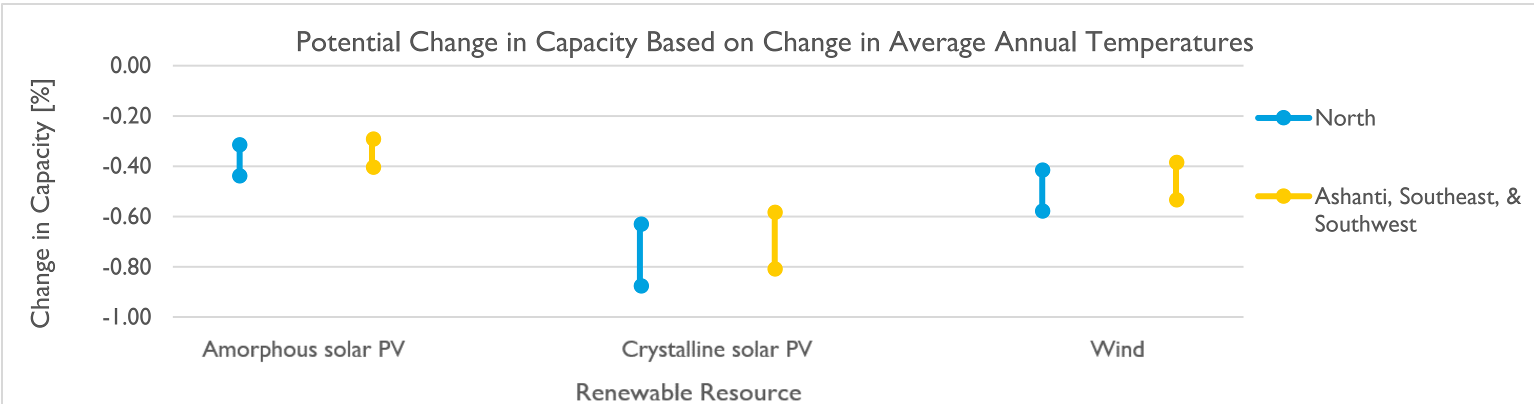



*Figure 25. Potential change in solar PV and wind capacity based on change in average annual temperature for the North and for Ashanti, the Southeast, and the Southwest regions for 2040-2059 relative to the historical period 1986-2015. The upper bound represents the change in capacity associated with RCP 4.5 projections, while the lower bound represents change in capacity associated with RCP 8.5 projections. Capacity-temperature relationship based on ADB 2012 and Solar Facts n.d.*

[118] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baselisne period of 1986-2015. Source: KNMI Climate Explorer.
[119] Bazyomo, S. D. Y. B., Agnidé Lawin, E., Coulibaly, O., & Ouedraogo, A. (2016). Forecasted Changes in West Africa Photovoltaic Energy Output by 2045. Climate, 4(4), 53.
[120] Asian Development Bank (ADB). (2012). Climate Risk and Adaptation in the Electric Power Sector.
[121] Solar Facts. n.d.. Photovoltaic Efficiency – Inherent and System. PV Education, http://www.solar-facts.com/panels/panel-efficiency.php.
[122] Bazyomo et al. 2016. Relationship: $\%\ Change\ in\ Output = -0.0079 * Year + 16$
[123] Asian Development Bank (ADB). (2012). Climate Risk and Adaptation in the Electric Power Sector.
[124] Bazyomo et al. 2016

## TABLE 8. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO RENEWABLES IN GHANA

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON RENEWABLES | IMPLICATIONS FOR GHANA |
| --- | --- | --- | --- |
| Extreme precipitation events | There is strong model agreement of projected increases in the proportion of precipitation that falls during extreme rainfall events, increasing the frequency and intensity of flooding. By mid-century, the proportion of precipitation falling during extreme rainfall ($99^{th}$ percentile) events is projected to increase the most in the North (24 to 26 percent) and slightly less in the other three zones (18 to 25 percent).[125] | Extreme precipitation and associated flooding are expected to directly damage generation infrastructure, biomass crops, and access roads, causing service disruptions and higher repair costs.<br><br>Extreme precipitation events and changes in wind patterns may alter wind potential. Wind turbines are intended to operate over a 50-year return period of conditions.[126] | Ghana's largest solar PV plant is currently on the coast within the Southeast region, and 62 percent of Ghana's renewable resource capacity is expected to lie within the low-lying coastal Southeast and Southwest in 2030, indicating that these plants may be vulnerable to damage from extreme precipitation and associated flooding. |
| Dry spells & drought | Projections for annual precipitation and consecutive dry days are mixed in sign. By mid-century, the model ensemble averages project a 1 to 2 percent increase in annual precipitation for all zones and a seasonal shift, with more occurring between the latter part of the rainy season and early part of the dry season (+3 to 5 percent), and less occurring during the early part of the rainy season (-2 percent). Consecutive dry days are projected to change by -0.7 to 0.7 percent in the North and increase by 0.8 to 1.1 percent in all other zones. Soil moisture content is projected to increase throughout the year, with annual average soil moisture content increasing by 2 percent in the North and 2 to 4 percent in the other zones, with the greatest increases coinciding with projected precipitation increases (October to December in the North and November to January in the other zones).[127] In Accra, mean dry spell duration is projected to increase slightly in all months but June, December, and January.[128] | During periods of decreased precipitation and increased consecutive dry days, there may be a decrease in water supply and increase in water competition, reducing the availability of cooling water for concentrated solar power (CSP) systems and biomass fuel yields. | The North is most at risk, as it has historically been drier than the rest and is projected to experience a greater increase in average annual temperature. One small (2 MW) solar PV plant is currently in the region, and by 2030 there will be three additional installations, totaling nearly 400 MW and 27 percent of Ghana's renewable resource capacity, the most of any region. |

[125] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[126] ASCE/AWEA. (2011). Recommended Practice for Compliance of Large Land-based Wind Turbine Support Structures.
[127] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[128] Climate Information Portal

**TABLE 8. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO RENEWABLES IN GHANA**

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON RENEWABLES | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Sea level rise | Throughout this century, sea level is expected to continue to rise, by 3 mm per year,[129] reaching 0.15 m by 2050 relative to the 1986-2015 historical period. Additionally, the frequency and intensity of tide-related waves and storm surge is expected to increase, exacerbating shoreline erosion, recession, and inundation.[130,131,132] By 2040, land loss due to submergence is expected to reach 2.59 to 3.09 $km^2$ per year and erosion is projected to reach 0.15 to 0.68 $km^2$ per year.[133] | These coastal hazards may lead to inundation of and direct damage to low-lying generation infrastructure, biomass plantations, and access roads.<br><br>Increased saltwater intrusion and exposure may increase corrosion of electrical components and damage to biomass plantations. | These impacts will most likely be severe in the coastal Southeast and Southwest. Ghana's largest solar PV plant is currently on the coast within the Southeast region, and 62 percent of Ghana's renewable resource capacity is expected to lie within the two regions in 2030. Should the future plants be installed along the coast, they will likely be exposed to these coastal hazards. |

[129] Boateng et al. 2017
[130] Boateng et al. 2017
[131] World Bank 2010
[132] Boateng 2012
[133] World Bank 2010

## RISKS TO TRANSMISSION AND DISTRIBUTION

Ghana's transmission system ranges from 69 kV to 330 kV and is made up of 5,100 km of lines and 54 transformer substations, as depicted in Figure 265, right.[134] Much of the existing infrastructure stems from the Akosombo dam and transmits electricity along the coast and from the coast to the north along the 330 kV backbone (blue) that cuts up the center of the country. The majority of the existing substations lie along the coastal lines or along a 330 kV backbone. The transmission infrastructure has had enough capacity to meet electricity needs as of 2014, additional lines are planned to reduce overloading, enhance reliability, and account for future increases in generation capacity.[135]

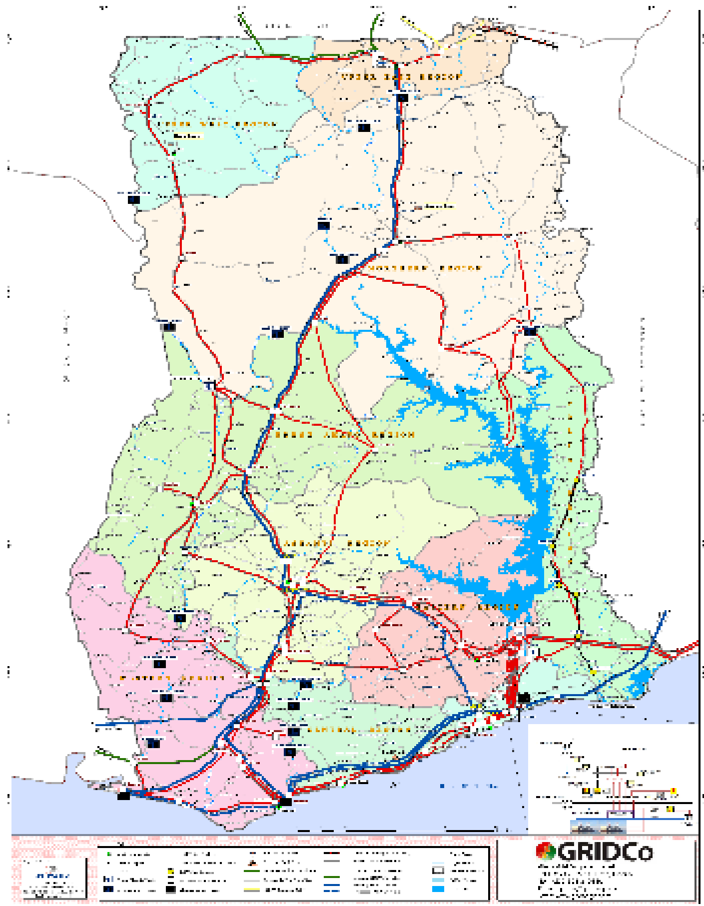


*Figure 26. Ghana existing (solid lines) and planned (hashed lines) transmission and distribution system. Lines range from 330 kV (blue), 225 kV (green), 161 kV (red and yellow), and 69 kV (black). White squares represent existing substations.*

Major planned lines include a 161 kV system transmitting electricity along the eastern border, the Coastal Interconnection which is a 330 kV line transmitting electricity along the coast from Accra to Takoradi to Domunli, and an additional 330 kV line transmitting electricity inland from Accra to Kumasi, seen in Figure 26.

Ghana's transmission and distribution system is vulnerable to a number of stressors, particularly extreme rainfall and flooding, sea level rise and coastal erosion, temperature, and drought. Extreme rainfall and flooding have historically had significant impacts economic and social development throughout the country. Of natural disasters and hazards, flooding is the second greatest cause of death after epidemics. Floods have historically impacted the power system; for instance in 1995, the Achimota Volta River Authority (VRA) substation in Accra was flooded after extreme rains, and resulted in power outages.[136]

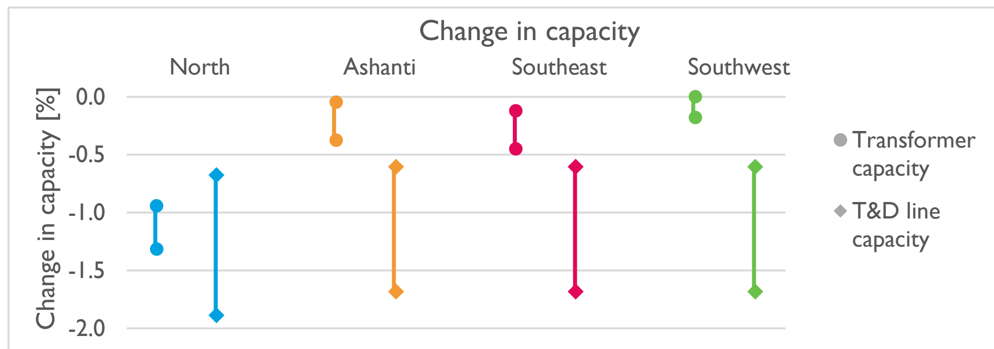
[134] Climate Investment Funds (CIF). 2015. Scaling-up Renewable Energy Program (SREP) in Ghana Investment Plan.
[135] GRIDCo. 2014. 2014 Electricity Supply Plan.
[136] Asumadu-Sarkodie, S., Owusu, P.A. and Rufangura, P. 2015. Impact analysis of flood in Accra, Ghana. Advances in Applied Science Research.

Ghana already experiences coastal erosion, flooding, and shoreline recession, primarily due to human impacts, mismanagement, sea level rise, increased storm intensity, and extreme rainfall.[137] These coastal hazards present challenges as a substantial number of substations and 330 kV and 161 kV lines are located along the coast. Increasing temperatures are also likely to pose a significant threat, as electricity distribution losses are already at 25 percent, in part due to increased ambient temperatures.[138]

The following section explores potential risks to Ghana's transmission and distribution system.[139]

[137] Boateng 2012
[138] World Bank 2010
[139] Based on the following sources: Ebinger and Vergara 2011, Hammer et al. 2011, Seattle City Light 2013, USAID 2012, and U.S. DOE 2016, and WECC 2014

## TABLE 9. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO TRANSMISSION AND DISTRIBUTION IN GHANA

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON TRANSMISSION & DISTRIBUTION | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Temperature increases and extremes | Average, minimum, and maximum temperatures are projected to increase in all zones. All models project increases in average annual temperature. By mid-century, the North is projected to experience a 1.3 to 1.8°C increase, while the other zones are projected to experience a 1.2 to 1.6°C increase.[140] By 2035, the Volta Basin is projected to experience a 1.0°C increase.[141] Agricultural irrigation demand is projected to increase by 4.2 to 8.4 percent by 2030.[142] | Increased temperatures reduce transmission and distribution line, transformer, and substation capacity. Per 1°C rise, transmission and distribution line and cable resistance increases by 0.4 percent, and load capacity decreases by 0.5 to 1 percent.[143]<br><br>Increasing temperatures are likely to drive an increase in demand and load, increasing transmission and distribution losses; average system losses increase by about 1.5 percent per 1 percent increase in load, and cooling demand increases by 10 to 15 percent per 1°C.<br><br>Line sag also increases with temperature, at a rate of 4.5 cm per 1°C.<br><br>The temperature limit of transmission and distribution lines is typically 80°C at the conductor surface.[144]<br><br>Transformers also experience negative impacts, with capacity decreasing by 0.7 percent per 1°C rise in ambient temperature above 30°C.[145] Temperature extremes can accelerate transformer aging and jeopardize operation and maintenance activities through labor restrictions. | The North has slightly higher exposure, given higher historical temperatures, temperatures will be more likely to exceed impact thresholds. While there are fewer planned lines in the North, there is a fair amount of existing transmission and distribution infrastructure in the region, including the 330 kV backbone. A decrease in the capacity of this mainline may present a challenge as the majority of power generation lies in the south, and the Northern areas rely on the backbone to transmit electricity up to their communities. The Southeast and Southwest areas face similar temperature increases, and are at high risk due to the large density of transmission and distribution lines. Illustrative potential capacity decreases for February and March (the hottest months of the year) based on simple temperature-efficiency relationships are presented in Figure 27. Based on changes in average monthly temperature in February and March temperature, these relationships indicate that by mid-century, capacity would decrease the most for transmission and distribution lines in the North (0.9 to 1.3 percent) and transformers in the North (0.7 to 1.9 percent).<br><br><br>*Figure 27. Change in transmission and distribution line and transformer capacity in February and March by mid-century (2040-2059) relative to 1986-2015 based on increase in monthly average temperature. For transformers, upper bounds represent ensemble means of RCP 4.5 while lower bounds represent ensemble means for RCP 8.5, both under a 0.7% capacity decrease per 1°C above 30°C. For lines, upper bounds represent ensemble means for RCP 4.5 under a 0.5% decrease in capacity per 1°C temperature rise while lower bounds represent ensemble means for RCP 8.5 under a 1.0% decrease in capacity per 1°C temperature rise.* |

[140] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[141] Based on results from the CCLM model for the A1B scenario for 2021-2050 relative to 1983-2012. Source: McCartney et al. 2012.
[142] Projections based on AquaCrop model for wet and dry scenarios for the country and the globe. Source: Amisigo et al. 2015.
[143] Asian Development Bank (ADB). (2015) Climate Risk and Adaptation in the Electric Power Sector.
[144] Sathaye, J., Dale, L., Larsen, P., and Fitts, G. (2012). Estimating Risk to California Energy Infrastructure from Projected Climate Change. CA Energy Comm.
[145] Sathaye et al. 2012

**TABLE 9. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO TRANSMISSION AND DISTRIBUTION IN GHANA**

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON TRANSMISSION & DISTRIBUTION | IMPLICATIONS FOR GHANA |
|---|---|---|---|
|  Extreme precipitation events | There is strong model agreement of projected increases in the proportion of precipitation that falls during extreme rainfall events, increasing high flows and the frequency and intensity of flooding. By mid-century, the proportion of precipitation falling during extreme rainfall (99th percentile) events is projected to increase the most in the North (24 to 26 percent) and slightly less in the other three zones (18 to 25 percent).[146] | Extreme precipitation and associated flooding are expected to directly damage infrastructure, scouring transmission tower bases and flooding substations and underground cables.<br>Extreme precipitation can lead to erosion at pole foundations, exposing underground cabling to water.<br>Transmission and distribution line capacity may increase due to convective cooling, so long as winds remain below damage levels. Capacity can increase by up to 20 percent per meter per second increase in wind speed.<br>In the past, extreme precipitation events have led to power outages due to flooding of substations,[147] burning of transformers,[148] lightning striking transmission lines[149] and power poles[150], and downing of power poles.[151] | Increases in extreme precipitation and associated flooding are likely to increase the severity of damages. These impacts will likely be most severe in areas which already experience severe flooding such as the Upper East, the Upper West, the Northern Region (that are in the "Northern-Ghana" model zone), the Western Region, the Sekondi-Takoradi Metropolis (that are in the "SouthWest-Ghana" zone), and Accra (in the SouthEast-Ghana zone), [152] as illustrated in Figure 28, below. As much of the transmission and distribution infrastructure is along the coast, sea level rise and storm surge may compound flood risk during extreme precipitation events, particularly if the areas have poor drainage systems.<br><br>*Figure 28. Flooding in Accra in 2016. Source: Fox, E. 2016. Floods leave many dead in southern Ghana. Aljazeera.* |

[146] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[147] Asumadu-Sarkodie et al. 2015; BBC News. 2015. Ghana petrol station inferno kills about 150 in Accra. http://www.bbc.com/news/world-africa-33003673
[148] GRIDCo. 2014. Ghana Grid Company Limited (GRIDCo) Annual Report 2013.
[149] Ocloo, D. R. 2017. Powerful lightning likely cause of nationwide blackout. Graphic Online. http://www.graphic.com.gh/news/general-news/powerful-lightning-disrupts-power-supply.html
[150] GNA. 2012. Sissala West District isolated by recent floods. Ghana News Agency (GNA). http://ghananewsagency.org/social/sissala-west-district-isolated-by-recent-floods-49518
[151] eTV Ghana. 2017. Brong Ahafo Region: Strong winds wreak havoc in Amangoase. http://etvghana.com/2017/02/27/brong-ahafo-region-strong-winds-wreak-havoc-in-amangoase/
[152] Kankam-Yeboah et al. 2011; Addo and Danso 2017

**TABLE 9. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO TRANSMISSION AND DISTRIBUTION IN GHANA**

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON TRANSMISSION & DISTRIBUTION | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Dry spells & drought | Projections for annual precipitation and consecutive dry days are mixed in sign. By mid-century, the model ensemble averages project a 1 to 2 percent increase in annual precipitation for all zones and a seasonal shift, with more occurring between the latter part of the rainy season and early part of the dry season (+3 to 5 percent), and less occurring during the early part of the rainy season (-2 percent). Consecutive dry days are projected to change by -0.7 to 0.7 percent in the North and increase by 0.8 to 1.1 percent in all other zones. Soil moisture content is projected to increase throughout the year, with annual average soil moisture content increasing by] 2 percent in the North and 2 to 4 percent in the other zones, with the greatest increases coinciding with projected precipitation increases (October to December in the North and November to January in the other zones).[153] In Accra, mean dry spell duration is projected to increase slightly in all months but June, December, and January.[154] Climate change is expected to increase the probability of long dry periods in many | During periods of decreased precipitation and increased consecutive dry days, increases in wildfires can directly damage transmission and distribution lines, lead to soot accumulation on insulators that can cause leakage, and result in ionized air and smoke that can act as a conductor and cause arcing between lines. | The North is most at risk, as it has historically been drier than the rest and is projected to experience a greater increase in average annual temperature. It also has a greater wildfire risk, as each year, 90% of the Northern Savannah is prone to wildfire,[156] seen in Figure 29,[157] left. Land area prone to wildfire is lowest in the central and southwestern parts of the country, with 30% of land area prone to wildfire annually in the High Forest and Transitional Zone. While there are fewer planned lines in the North, there is a fair amount of existing transmission and distribution infrastructure in the region, including the 330 kV backbone. Damage to this mainline may present a challenge as the majority of the power generation lies in the south and the Northern areas rely on the backbone to transmit electricity up to their communities. |

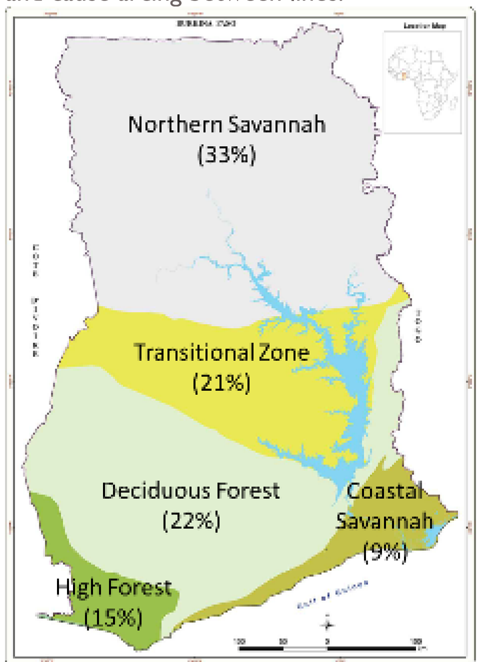



*Figure 29. Ghana ecoregions. Source: modified from Ekpe et al. 2014*

[153] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[154] Climate Information Portal
[156] Ghana Ministry of Lands, Forestry & Mines. 2006. Ghana National Wildfire Management Policy.
[157] Ekpe, E. K., Hinkle, C. R., Quigley, M. F., & Owusu, E. H. 2014. Natural resource and biodiversity conservation in Ghana: the use of livelihoods support activities to achieve conservation objectives. International Journal of Biodiversity Science, Ecosystem Services & Management, 10(4), 253-261.

**TABLE 9. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO TRANSMISSION AND DISTRIBUTION IN GHANA**

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON TRANSMISSION & DISTRIBUTION | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| | areas in Ghana, increasing the wildfire risk.[155] | | |
| Sea level rise | Throughout this century, sea level is expected to continue to rise, by 3 mm per year,[158] reaching 0.15 m by 2050 relative to the 1986-2015 historical period. Additionally, the frequency and intensity of tide-related waves and storm surge is expected to increase, exacerbating shoreline erosion, recession, and inundation.[159,160,161] By 2040, land loss due to submergence is expected to reach 2.59 to 3.09 $km^2$ per year and erosion is projected to reach 0.15 to 0.68 $km^2$ per year.[162] | These coastal hazards may lead to scouring of transmission tower bases, water damage to coastal and underground substations and lines, and increased salt-water exposure, leading to corrosion of electrical components, particularly for coastal buried lines. | These impacts will most likely be severe in the coastal Southeast and Southwest. A significant portion of Ghana's planned and existing transmission and distribution lines and substations lie along the coast, in potentially low-lying areas, indicating that they will could be highly exposed to sea level rise, storm surge, and shoreline erosion. Flooding due to sea level rise and storm surge may be compounded by extreme precipitation events, particularly in areas with poor drainage systems. |

[155] Appiah, M., Damnyag, L., Blay, D. and Pappinen, A. 2010. Forest and agroecosystem fire management in Ghana. Mitigation and adaptation strategies for global change, 15(6), pp. 551-570.
[158] Boateng et al. 2017
[159] Boateng et al. 2017
[160] World Bank 2010
[161] Boateng 2012
[162] World Bank 2010

## RISKS TO DEMAND

As illustrated in Figure 30, right, electricity transmission is relatively stable over the course of the year, with a 25% difference between the minimum and maximum monthly values.[163]

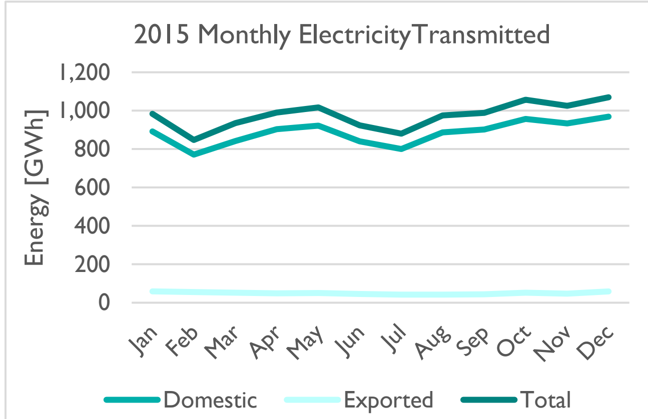



*Figure 30. Monthly electricity transmission for 2015. Source: GRIDCo*

By 2030, Ghana's total annual energy and peak demand are projected to double relative to 2016 levels, as per the draft IRRP Reference Case. As illustrated in Figure 31, below, the Southeast is projected to experience the greatest volume increase (8,200 GWh in energy demand and 1,300 MW in peak load) while the North is projected to experience the greatest percent increase (about 190 percent in energy and peak demand). The Southwest and Ashanti are projected to experience the least amount of change, as per the draft IRRP Reference Case.

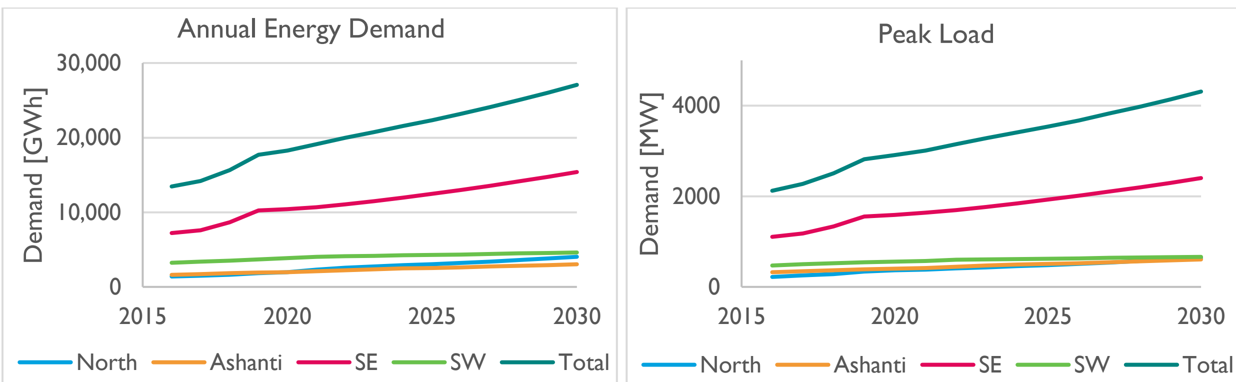



*Figure 31. Current and projected total energy demand (left) and peak energy demand (right) for 2015 through 2030. Source: ICF 2017*

Cooling degree days (CDD) are projected to increase by 20 to 27 percent in Ghana, with the greatest magnitude increases occurring in the north (667 to 904 CDD) and the greatest percent increases occurring in Ashanti (20 to 28%), as shown in Figure 32, right.[164] This increase in CDD is likely to drive an increase in cooling demand.

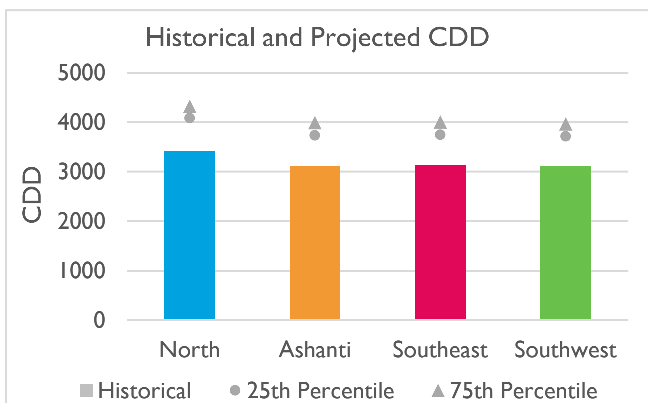



*Figure 32. Historical (colored blocks) and projected (grey points and triangles) CDD. Projected values are a2 25th and 75th percentile model values for 2046-2065 relative to 1961-1999. Source: Climate Wizard.*

[163] GRIDCo. 2016. Ghana Grid Company Limited (GRIDCo) 2015 Annual Report.
[164] 25th to 75th percentile of models under an a2 emissions scenario for 2046-2065 relative to 1961-1999

## TABLE 10. PROJECTED CHANGE IN CLIMATE AND POTENTIAL CLIMATE IMPACTS TO RENEWABLES IN GHANA

| CLIMATE STRESSOR | CHANGE IN CONDITION | IMPACTS ON DEMAND | IMPLICATIONS FOR GHANA |
|---|---|---|---|
| Temperature increases and extremes | Average, minimum, and maximum temperatures are projected to increase in all zones. All models project increases in average annual temperature. By mid-century, the North is projected to experience a 1.3 to 1.8°c increase, while the other zones are projected to experience a 1.2 to 1.6°c increase.[165] Additionally, solar radiation is projected to decrease in Ghana by 0.21 W/m$^2$/year through 2100.[166] | Increased temperatures increase energy demand for cooling, stressing energy system capacity. More specifically, a large number of studies suggest that cooling demand can increase by 10 to 15 percent per 1°C rise.[167] Additionally, increased temperatures lead to increased energy demands for irrigated crops, including biofuels. | The North is most at risk as it has historically experienced the highest temperatures and is projected to experience the greatest temperature increase. As illustrated in Figure 33, the North has the potential to experience a 13 to 26 percent increase in demand while the other three regions have the potential to experience a 12 to 18 percent increase in demand based on change in average annual temperatures. However, this increase in demand is dependent upon the penetration of air conditioning throughout these areas. |
| Dry spells & drought | Projections for annual precipitation and consecutive dry days are mixed in sign. By mid-century, the model ensemble averages project a 1 to 2 percent increase in annual precipitation for all zones and a seasonal shift, with more occurring between the latter part of the rainy season and early part of the dry season (+3 to 5 percent), and less occurring during the early part of the rainy season (-2 percent). Consecutive dry days are projected to change by -0.7 to 0.7 percent in the North and increase by 0.8 to 1.1 percent in all other zones. Soil moisture content is projected to increase throughout the year, with annual average soil moisture content increasing by 2 percent in the North and 2 to 4 percent in the other zones, with the greatest increases coinciding with projected precipitation increases (October to December in the North and November to January in the other zones).[168] In Accra, mean dry spell duration is projected to increase slightly in all months but June, December, and January.[169] | During periods of decreased precipitation and increased consecutive dry days, energy use may increase due to increased agricultural water demand and associated irrigation water pumping. | Areas with irrigated agriculture and non-irrigated agriculture that begins to require irrigation due to increased dryness are likely to experience increased irrigation and associated energy pumping demands. |

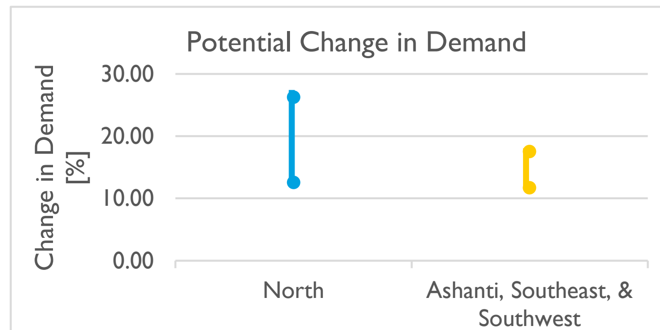



*Figure 33. Potential change in demand based on changes in average annual temperature for 2040-2059 relative to the historical period 1986-2015. The upper bound represents the change in demand associated with the ensemble average of RCP 4.5 and a 10% increase in demand per 1°C increase, while the lower bound represents change in demand associated with the ensemble average of RCP 8.5 and a 15% increase in demand per 1°C increase.*

[165] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[166] Bazyomo, S. D. Y. B., Agnidé Lawin, E., Coulibaly, O., & Ouedraogo, A. (2016). Forecasted Changes in West Africa Photovoltaic Energy Output by 2045. Climate, 4(4), 53.
[167] Sathaye et al. 2012
[168] Projections represent ensemble averages of RCP 4.5 and RCP 8.5 for 2040-2059 relative to the baseline period of 1986-2015. Source: KNMI Climate Explorer.
[169] Climate Information Portal

# BUIDLING CLIMATE RESILIENCE INTO GHANA'S POWER SECTOR

Incorporating climate considerations into power sector planning helps to ensure that projects and plans effectively and efficiently meet their objectives given potential changes in climate. Furthermore, undertaking resilience efforts at the outset represents a prudent and cost-effective approach to reduce potential costly future damages and disruptions as a result of climate change. Climate change can be considered at the asset level or at the system level, and factor into a diverse array of policies, planning, and projects.

Ghana's Nationally Determined Contribution (G-NDC) highlights sustainable energy security as one of its priority sectors.[170] While the document primarily describes sustainable energy security as a mitigation action, the energy resource diversification that the document calls for would enhance the resilience of the energy system. The document also highlights several policy actions that are aimed at achieving the country's adaptation goals and would lead to enhanced energy resilience, as listed in Table 11, below. This document is complemented by Ghana's more recent National Climate Change Adaptation Strategy, which lists energy sector adaptation on the demand- and supply-side as a priority program.[171]

**TABLE 11. GHANA'S ADAPTATION AND MITIGATION POLICY ACTIONS IN THE ENERGY SECTOR, AS LISTED IN GHANA'S G-NDC (2015)**

| MITIGATION POLICY ACTIONS | ADAPTATION POLICY ACTIONS |
|---|---|
| • Scale up renewable energy penetration by 10% by 2030<br>• Promote clean rural household lighting<br>• Expand the adoption of market-based cleaner cooking solutions<br>• Double energy efficiency improvement to 20% in power plants | • City-wide resilient infrastructure planning, including energy<br>• Early warning and disaster prevention, including expanding and modernizing 22 synoptic stations based on needs assessment, and increasing number to 50 stations for efficient weather information management<br>• Integrated water resources management |

In this section, a range of strategies to build the climate resilience of the power sector are summarized, starting from the importance of understanding, identifying, and prioritizing climate risks to identifying adaptation measures across the power system value chain

### UNDERSTANDING, IDENTIFYING, AND PRIORITIZING CLIMATE RISKS

First, power planners need to understand climate change and be aware not only of the physical impacts, but also how it may ultimately impact their bottom-line finances, reputation, and ability to meet regulations. As outlined above, Ghana's power system is subject to a diverse array of climate-related stressors whose projected magnitude and impact varies by location and power system component. A

[170] Republic of Ghana. 2015. Ghana's nationally determined contribution (G-NDC) and accompanying explanatory Note.
[171] UNEP and UNDP 2016

first step is to build the capacity of power sector stakeholders to understand these risks, a critical starting point for helping to ensure that climate risk management is prioritized.

To be efficient in time and resources, power sector stakeholders can take a hierarchical approach that moves from high-level risk screening (country, power sector-level screening) to more detailed assessment where risks may be more consequential (e.g., project analysis and engineering design). Climate vulnerability and risk analyses can increase in detail, focus, and complexity (and cost) during successive project planning stages, depending on the degree of potential risk identified through screening in earlier stages. The IRRP project represents a high-level risk screening analysis, which identifies key vulnerabilities that power planners should be aware of and take into consideration in their power system master plan.

## IDENTIFICATION OF ADAPTATION MEASURES

Climate risk and uncertainty assessment is important for identification and prioritization of risks, and ultimately for identification of priority adaptation needs and selection of measures. Adaptation measures can be targeted to manage different climate risks, and can include the selection of a portfolio of structural, technological, operational, and planning measures for different power system components. At the project level, project teams can identify adaptation measures in pre-feasibility studies and feasibility and engineering design. Different components of the energy system will require different responses as discussed in the following sections. Box 2, right, discusses modifications undertaken by a hydropower plant in Tajikistan to adapt to climate change.

There are a range of measures that are increasingly being employed to improve system efficiencies, thereby reducing power system stress and increasing the margin of resiliency of the power system.

> Box 2. Hydropower Plant Design Modifications Due to Climate Change
>
> Tajikistan's Qairokkum hydropower plant will be rehabilitated to bolster the plant's resilience to climate change. The utility is integrating climate resilience into its operations by:
>
> - Implementing **advanced training** focused on climate diagnostics, climate risk assessments, and seasonal forecasting;
> - Updating its **operating rules** to maximize generation, minimize spills, and optimize safety, and improve flood emergency response; and
> - Enhancing **data management and sharing** by developing a protocol on using climatological and hydro-meteorological data for hydropower operations.
>
> The utility is further enhancing its resilience and taking advantage of projected higher peak flows by installing new, more efficient turbines that will increase installed capacity from 142 to 170 MW.
>
> **Sources**: IHA. (2016). Hydropower Status Report; Baum, P. (2015). Climate Resilience and Hydropower: EBRD Case Study – HPP Qairokkum. European Bank.

**No-regrets** measures include energy efficiency and demand-side management strategies that provide some margin for utilities to better withstand climate events that might increase peak demands, such as during heatwaves. No-regrets measures are proactive measures that are beneficial to the power system regardless of climate change.

**Low-regrets** strategies have modest cost or regrets implications, while the benefits under future climate change conditions are potentially large, albeit uncertain. Many of the adaptation contributions listed in Ghana's G-NDC (Table 11, above) would be considered no- or low-regrets measures.

**Climate-justified** strategies are those that explicitly take into consideration future climate change, and are considered most beneficial if the potential climate change conditions incorporated into the decisions being taken are realized. Climate-justified adaptation strategies might be considered in project design alternatives, and often require a more detailed, rigorous risk assessment. For example, in cases where climate change could have a significant impact, certain types of power infrastructure investments may be appropriate. These may be highly capitalized, unique, or irreversible, such as engineering structures with long lifetimes, and have both long-lived benefits and costs. For these investments, changes in climate and variability can have a significant impact on the design and operations of infrastructure.

In general, no-regrets strategies may be easier to justify, and cheaper to implement, while serving multiple objectives, but in some instances they may only marginally increase resilience. On the other hand low-regret or climate-justified adaptation measures may be harder to justify, and more expensive to implement, but could result in far greater resilience. In addition, flexibility can be built into planning and engineering, which may allow for delayed implementation of more costly measures over time.

The following sections describe resilience measures that are unique to a specific power sector component, divided by generation, T&D, and demand-side management. The effectiveness of some of these measures can and will be evaluated quantitatively in the IRRP project and power system modeling, while other measures (such as structural design changes) may require more detailed engineering and cost analysis. For example, the effectiveness of demand-side measures to reduce system stress, and some land use and operational management changes will be considered in the power systems and hydropower modeling. Other investments, for example, in monitoring and evaluation, are designed to improve knowledge and understanding of potential impacts and effectiveness of different adaptation investments, and may be integrated into power system master planning.

## BUILDING RESILIENCE INTO POWER GENERATION

Ghana intends to pursue various adaptation strategies to increase its renewables portfolio thereby enhancing the resilience of its generation resources, as outlined in its G-NDC. The G-NDC commits to scaling up the use of renewable energy sources and to significantly increase the energy efficiency of power plants. These commitments are reflective of broader planning and management efforts, which can be complemented by strategies geared toward managing risks to specific generation types.

While many adaptation strategies are unique to specific climate stressors and generation types, some apply to all stressors and generation types or to the entire generation network. Due to existing shortages in electricity supply, Ghana has already begun to pursue a number of these strategies that focus on expanding generation sources. However, there are additional strategies that Ghana has not yet undertaken that focus on planning and design or backup infrastructure to account for climate change. These strategies, their type (policy and planning or structural), and whether Ghana has begun to pursue them are described in Table 12, below.

Adaptation options specific to Ghana's generation sources and climate stressors, and the regions in which they are particularly applicable, are summarized below in Table 13. Note that risks will vary across the zones. The section provides a high-level snapshot of risks across zones given current and projected climate, and the potential generation assets at risk.

Ghana is also already undertaking a number of coastal protection policies. These measures include flood drainage and management systems, coastal protection infrastructure, and coastal zone management.

**TABLE 12. ADAPTATION STRATEGIES APPLICABLE TO ALL GENERATION TYPES, AND WHETHER THEY ARE ALREADY BEING PURSUED IN GHANA[172]**

| JUSTIFICATION | TYPE | ADAPTATION STRATEGY | ALREADY PURSUING? |
|---|---|---|---|
| No-regrets | Technology | Invest in improved short-term (daily/monthly) weather prediction to improve load forecasts and operational management. | N |
| | | Use seasonal and annual weather forecasts to improve hydropower reservoir management. | Y |
| | Policy & Planning | Plan for provision of standby energy equipment and backup restoration supplies, as part of ancillary services. | N |
| | | Allow for flexible maintenance schedules for thermal generation, in order to account for changing rainfall patterns due to climate change. | N |
| | | Ensure that drafting of individual hydropower reservoirs are consistent with the expected long-term average of storage capacities, considering potential climate change impacts. | N |
| Low-regrets | Policy & Planning | Choose generation infrastructure sites that are not at high climate exposure risks, accounting for projected changes in coastal and riverine flooding. | N |
| | | Review and update power infrastructure design thresholds using climate change projections. | N |
| | Structural | Install backup systems for critical hospital and home needs. | Y |
| | | Invest in decentralized power generation (e.g., rooftop PV). | Y |
| | | Expand networks, network protection, and energy storage to enhance reliability. | Y |
| | | Build additional generation capacity to account for decreased generation efficiency or increased customer loads due to climate impacts. | N |
| Climate-justified | Policy & Planning | Ensure adequate backup generation and cooling systems for plants facing increased exposure to flooding, drought, and other extremes. | N |
| | Structural | Relocate or reinforce key generation infrastructure to reduce exposure and sensitivity to sea level rise, storm surge, extreme precipitation and floods, drought, extreme temperature, and other extreme weather events. | N |

[172] Based on tables from MCC, 2016. Original sources include Ebinger and Vergara, 2011; Hammer et al., 2011; Seattle City Light, 2013; USAID, 2012; U.S. DOE, 2016; and WECC, 2014.

## TABLE 13. ADAPTATION STRATEGIES BY CLIMATE STRESSOR, GENERATION TYPE, ZONE(S) WITH ESPECIALLY HIGH RISK WHERE ADAPTATION IS PARTICULARLY APPLICABLE, AND REGRET LEVEL[173]

| CLIMATE STRESSOR(S) | ADAPTATION STRATEGY | GENERATION TYPE | JUSTIFICATION | ZONE RISK DESCRIPTION |
|---|---|---|---|---|
| Drought | Secure adequate water supply through enhancements to water use efficiencies and conservation. | Thermal, Hydropower | No-regrets | While the **North** has historically been warmer and drier than the other zones and is projected to experience a slightly higher increase in average annual temperature, it has fewer existing and planned generation plants. Meanwhile, the **Southeast** and the **Southwest** have historically been slightly cooler and wetter and are projected to undergo a slightly lower temperature increase, but contain the majority of generation resources. **Ashanti** is historically the coolest and second wettest and projected to undergo similar changes to the Southeast and Southwest, and contains the least amount of existing and planned generation resources, indicating that it is less at risk than the other zones. |
| | Equip plants with technologies that capitalize on water reuse. | Thermal | Low-regrets | |
| | Couple improvements in short-term and seasonal hydrologic forecasting to analyses of long-term climate change to improve management and operational decisions (e.g., to maintain more carryover reservoir storage into the dry season and early part of the rainy season and reduce discretionary reservoir water releases). | Hydropower | Low-regrets | |
| | Evaluate operational changes (reservoir rule curve changes) assuming climate change to optimize energy output, given other constraints and water priorities. | Hydropower | Low-regrets | |
| | Invest in biomass crops that tolerate drought | Renewables | Low-regrets | |
| | Secure adequate water supply through contracts and contingencies based on an understanding of future hydrology. | Hydropower | Climate-justified | |
| | Reduce supply sensitivity to loss of hydropower availability by increasing reservoir system capacity. | Hydropower | Climate-justified | |
| | Retrofit power plants with additional cooling equipment and processes, including dry cooling technologies in water-limited areas. | Thermal | Climate-justified | |

[173] Based on the following sources: (a) Ebinger, J. and Vergara, W. (2011). Climate Impacts on Energy System: Key Issues for Energy Sector Adaptation. Energy Sector Management Assistance Program (ESMAP) and World Bank); (b) Hammer, S. A., J. Keirstead, S. Dhakal, J. Mitchell, M. Colley, R. Connell, R. Gonzalez, M. Herve-Mignucci, L. Parshall, N. Schulz, M. Hyams. (2011). Climate Change and Urban Energy Systems. Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network, C. Rosenzweig, W. D. Solecki, S. A. Hammer, S. Mehrotra, Eds., Cambridge University Press, Cambridge, UK, 85–111.; (c) Seattle City Light. (2013). Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan; (d) U.S. Agency for International Development (USAID). (2012). Energy Systems: Addressing Climate Change Impacts on Infrastructure: Preparing for Change; (e) U.S. Department of Energy (DOE). (2016). Climate Change and the Electricity Sector: Guide for Assessing Vulnerabilities and Developing Resilience Solutions to Sea Level Rise; (f) Western Electricity Coordinating Council (WECC). 2014. Assessment of Climate Change Risks to Energy Reliability in the WECC Region.

| CLIMATE STRESSOR(S) | ADAPTATION STRATEGY | GENERATION TYPE | JUSTIFICATION | ZONE RISK DESCRIPTION |
|---|---|---|---|---|
| Temperature Increases & Extremes | Prepare emergency contingency plans to ensure adequate cooling water to cope with high temperatures, accounting for competing water demands. | Thermal | No-regrets | While the **North** has historically experienced the highest temperatures and is projected to experience the greatest temperature increase, it has few existing and planned generation plants. Meanwhile, the **Southeast** and the **Southwest** have historically been slightly cooler and are projected to undergo a slightly lower temperature increase, but contain the majority of generation resources. **Ashanti** is historically the coolest and projected to undergo increases similar to the Southeast and Southwest, and contains the least amount of existing and planned resources, indicating that it is less at risk than the other zones. |
| | Leverage designs that improve passive airflow beneath PV mounting structures under increased extreme and average temperatures, reducing panel temperature and increasing power output; choose modules with more heat-resistant PV cells and module materials designed to withstand short peaks of very high temperature. | Renewables: Solar | Climate-justified | |
| | Install steam-powered chillers to reduce burden on local power system on hot days. | Thermal | | |
| | Build flexibility into the original plant design to allow for changes in the future. | All | Low-regrets | |
| Precipitation & flow variability & timing | Site solar PV systems where expected changes in cloud cover are relatively low. | Renewables: Solar | No-regrets | The **northern** parts of the Volta in Ghana have historically received the least total annual rainfall and are projected to experience similar changes in total annual rainfall relative to the other zones, but only contains one hydropower plant. Meanwhile, the **southeastern** part of the basin is historically slightly cooler and wetter and projected to undergo similar changes in total annual rainfall, but contains over three quarters of Ghana's available hydropower capacity and nearly one third of the country's total available capacity. Additionally, should water availability decrease and/or water requirements increase upstream (in the north), water availability may decrease downstream (in the southeast). |
| | Evaluate reservoir rule curve changes assuming climate change to optimize energy output, given other constraints and water priorities. | Hydropower | Low-regrets | |
| | Develop improved hydrological forecasting techniques and adaptive management operating rules. | Hydropower | | |
| | Modify operation of the existing reservoirs and spillways to take into consideration variable and changing flow amounts. | Hydropower | | |
| | Consider increased potential of severe flooding events for the design of future hydropower plants. | Hydropower | Climate-justified | |

| CLIMATE STRESSOR(S) | ADAPTATION STRATEGY | GENERATION TYPE | JUSTIFICATION | ZONE RISK DESCRIPTION |
|---|---|---|---|---|
| Extreme precipitation and erosion and sedimentation due to increased precipitation intensity | Protect watershed to secure adequate water supply to reduce silt loading and attenuate peak flow. | Hydropower | No-regrets | These impacts will likely be most severe in areas which already suffer from flooding. Accra, located in the **Southeast**, contains a large number of generation resources (mainly thermal) and already suffers from severe flooding, which is likely to be exacerbated by projected increases in frequency and intensity of extreme precipitation events. |
| | Employ sediment expulsion technology. | Hydropower | Low-regrets | |
| | Implement erosion control measures to reduce siltation and sedimentation. | Hydropower | | |
| | Integrate water resource management approaches in the basin and develop water regulations that reflect climate change. | All | | |
| | Restore and better manage upstream land including afforestation to reduce floods, erosion, silting, and mudslides. | All | | |
| | Retrofit existing generation facilities to prepare for flood conditions. | Hydropower | Climate-justified | |
| | Consider projected changes in inflows and precipitation patterns during the design phase of the turbines and the spillways. | Hydropower | | |
| | Modify design of the reservoir and spillways to take into consideration expected higher flows. | Hydropower | | |
| | Modify spillway capacities and install controllable spillway gates to flush silted reservoirs. | Hydropower | | |
| Sea level rise, storm surge, & coastal erosion | Require utilities to develop storm-hardening plans on a regular basis. | All | No-regrets | The **Southeast** and **Southwest** will are most vulnerable as they contain land along the coast. |
| | Develop siting rules for new coastal power plants to minimize flood risk. | Thermal | Low-regrets | |
| | Design turbines, systems, and structures to better handle changing wind speeds and to capture greater wind energy with taller towers. | Renewables: Wind | Climate-justified | |

## BUILDING RESILIENCE INTO TRANSMISSION AND DISTRIBUTION

While Ghana's G-NDC does not specify any commitments to enhancing the resilience of its transmission and distribution network, there are plans to expand the system in ways that would increase redundancy.[175] Multiple additional no- and low- regrets strategies exist that would build resilience to current and future stressors, as outlined in Table 14, below.

**TABLE 14. ADAPTATION STRATEGIES APPLICABLE TO TRANSMISSION AND DISTRIBUTION NETWORK, INDEPENDENT OF CLIMATE STRESSOR[174]**

| JUSTIFICATION | TYPE | ADAPTATION STRATEGY | ALREADY PURSUING? |
|---|---|---|---|
| No-regrets | Technology | Automate restoration procedures to bring energy system back on line faster after weather-related service interruption. | N |
| No-regrets | Operations & Maintenance | Regularly inspect vulnerable infrastructure (e.g., wooden utility poles). | Y |
| No-regrets | Operations & Maintenance | Update aging T&D equipment. | Y |
| No-regrets | Operations & Maintenance | Invest in improvements to short- and medium-term weather, climate, and hydrologic forecasting to improve lead times for event preparation and response. | N |
| Low-regrets | Operations & Maintenance | Increase resources for more frequent maintenance. | Y |
| Low-regrets | Structural | Support variable and distributed generation, through smart grid improvements. | Y |
| Low-regrets | Structural | Build additional transmission capacity to cope with increased loads and to increase resilience to direct physical impacts. | Y |
| Low-regrets | Structural | Build additional generation capacity to account for increased line losses and weather-related infrastructure damage. | N |
| Low-regrets | Structural | Install guy wires to poles and other structures in at high climate risk areas. | Y |

There also exist a number of adaptation strategies that address risks posed by specific climate stressors. Adaptation options addressing these stressors are outlined in Table 15, below.

[174] Based on tables from MCC, 2016. Original sources include Ebinger and Vergara, 2011; Hammer et al., 2011; Seattle City Light, 2013; USAID, 2012; U.S. DOE, 2016; and WECC, 2014

[175] ICF 2017

**TABLE 15. ADAPTATION STRATEGIES FOR TRANSMISSION AND DISTRIBUTION BY CLIMATE STRESSOR, APPROACH TYPE, ZONE(S) WITH ESPECIALLY HIGH RISK WHERE ADAPTATION IS PARTICULARLY APPLICABLE, AND REGRET LEVEL [176]**

| CLIMATE STRESSOR(S) | ADAPTATION STRATEGY | APPROACH TYPE | JUSTIFICATION | ZONE RISK DESCRIPTION |
|---|---|---|---|---|
| Drought | Increase fire corridors around transmission lines. | Land Use Planning | No-regrets | The **North** has historically been the driest, experienced the highest temperatures, is projected to experience slightly greater temperature increases, and relies heavily upon one main transmission line to bring electricity to its communities. At the same time, the density of transmission and distribution lines in the coastal **Southeast** and **Southwest** increases exposure, and reductions in efficiency or disruptions in electricity would significantly affect the economy and populations, particularly urban areas such as Accra which particularly rely on electricity for cooling due to the urban heat island effect.[177] |
| | Collaborate with adjacent landowners to reduce wildfire hazard along transmission lines and near other critical infrastructure. | | | |
| Average & extreme temperature | Create "green" buffers around T&D infrastructure to reduce tree contact with sagging lines due to extreme temperatures. | Land Use Planning | No-regrets | |
| | Install cooling and heat tolerant materials/technology at substations. | Structural | Climate-justified | |
| | Install cooling systems for transformers. | | | |
| | Use transmission line materials that can withstand higher temperatures. | | | |
| Extreme precipitation, flooding, sea level rise, & storm surge | Map landslide risk along transmission line rights-of-way. | Policy and Planning | No-regrets | These impacts will likely be most severe in the **Southeast** and **Southwest** which contain a significant amount of transmission and distribution infrastructure, are coastal, and contain low-lying areas which already experience severe flooding, such as in the Volta Delta and Accra. |
| | Consider extreme events threats in new siting. | | | |
| | Elevate or relocate substations to reduce potential flooding hazards. | Structural | | |
| | Relocate, or reinforce or replace towers/poles with stronger materials or additional support to decrease susceptibility to wind and flood damage. | | | |
| | Construct levees, berms, floodwalls, and storm surge barriers to protect exposed T&D infrastructure. | Structural | Climate-justified | |
| | Use submersible equipment that can withstand corrosion from salt-water exposure in vulnerable locations. | | | |
| | Install in-building supply systems (thermal or power) at elevations above anticipated flooding levels. | | | |
| | Place transmission lines underground. | | | |

176 Based on tables from MCC, 2016. Original sources: Ebinger and Vergara 2011; Hammer et al. 2011; Seattle City Light 2013; USAID 2012; U.S. DOE 2016; and WECC 2014

177 Manu, A., Twumasi, A.Y. and Coleman, L.T. 2006. Is it the result of global warming or urbanization? The rise in air temperature in two cities in Ghana. In Promoting Land Administration and Good Governance 5th FIG Regional Conference. Accra, Ghana.

## DEMAND-SIDE MANAGMEENT AND ENERGY EFFICIENCY

Ghana's National Climate Change Adaptation Strategy specifically calls for demand-side measures to adapt the national energy system to impacts of climate change.[178] As air conditioning continues to penetrate, it is important to implement demand-side management and energy efficiency measures to reduce stress on Ghana's energy system. The adaptation strategy also calls for increased use of energy efficient appliances.[179] Ghana's G-NDC also identifies improvement of power plant energy efficiency as a key mitigation strategy, though it also enhances resilience. Some examples of specific demand-side management adaptation options and whether they are being pursued by Ghana are listed below in Table 16.

**TABLE 16. DEMAND-SIDE MANAGEMENT ADAPTATION STRATEGIES[180]**

| JUSTIFICATION | TYPE | ADAPTATION STRATEGY | ALREADY PURSUING? |
|---|---|---|---|
| No-regrets | Policy and Planning | Establish public education programs to promote lifestyles that are less energy-dependent. | Y |
| | | Explore energy market mechanisms to meet demand. Consider power exchange agreements, purchasing from the spot market, and options purchasing. | Y |
| | | Establish or expand demand-response programs which encourage consumers to voluntarily reduce power consumption during peak demand events. | N |
| | | Time of Use Tariffs to encourage consumers to reduce power consumption during peak hours. | N |
| | | Improve and enforce energy-efficient building codes. | Y |
| | | Adopt mandatory minimum energy performance standards for appliances (including air conditioners). | Y |
| | | Adopt mandatory minimum energy performance standards for commercial buildings. | N |
| | Policy and Planning, Structural | Install smart meters and smart grid equipment to reduce power consumption during peak demand events. | N |
| | Structural | Employ passive building design architecture to maintain minimum comfort or lighting levels even in situations where energy system losses occur. | N |

[178] UNEP and UNDP 2016
[179] UNEP and UNDP 2016
[180] Based on tables from MCC, 2016. Original sources include Ebinger and Vergara, 2011; Hammer et al., 2011; Seattle City Light, 2013; USAID, 2012; U.S. DOE, 2016; and WECC, 2014.

# INTEGRATING CLIMATE CHANGE INTO POWER SYSTEMS PLANNING

Power planners need to recognize limitations and uncertainties when gathering and applying climate information to inform their decision making and investments. In Ghana, climate change projections are particularly uncertain for future precipitation. In addition, there is a lack of easily available, accessible, and useful data to conduct meaningful climate analysis in many locations in Ghana.[181] However, uncertainty or lack of complete data is not a reason for inaction. Rather, there is a need to plan robust strategies to prepare for uncertain futures.

New or modified energy planning frameworks and approaches can be applied to help planners meet their goals, given significant uncertainties. For example, the IRRP project uses a scenario planning approach to develop a small but wide-ranging set of future scenarios to test and improve the robustness of planning decisions; scenarios and sensitivity analysis can also be undertaken through existing power system models. Testing a diverse portfolio of investments and adaptation strategies given different scenarios or assumptions can help to identify portfolios that minimize risk against uncertain future scenarios. This "robust decision making" approach in an IRRP can help to identify decisions that are likely to perform well over a wide range of potential futures, and typically involves engaging stakeholders to consider trade-offs of investment choices.

New or modified energy planning frameworks and approaches can be applied to help planners meet their goals, given significant uncertainties. Ultimately, the IRRP approach allows for a better understanding of power system resilience against a range of climate and non-climate risks.

### INTEGRATED RESOURCES AND RESILIENCY PLANNING FOR BUILDING CLIMATE RESILIENT POWER PLANS

IRRP explicitly incorporates climate risks and resilience through a participatory planning process to identify power options that serve the public good and meet development objectives such as ensuring energy security, reducing sector inefficiencies, and reducing electricity costs. IRRP is being applied in Ghana to identify and assess the performance of different investment strategies given different growth and risk scenarios to inform a new power system master plan. These investment strategies can be defined to represent different objectives, which may be based on meeting load projections, policy conditions and financial constraints. The final power system master plan will reflect a least-regrets resource plan, based on stakeholder-defined metrics.

As part of the participatory approach, power sector stakeholders will identify priority investment strategies, what metrics to apply in order to evaluate strategies, and what scenarios to apply for consideration in planning. For example, power sector stakeholders may want to consider alternative investment strategies that require 20 percent non-hydro renewables in the resource mix by 2030, stipulate limiting carbon emissions, or target specific electricity import and/or export levels. These

[181] Although there is a significant amount data from weather stations at the Ghana Meteorological Agency, the data is not freely available.

alternative strategies could be considered against a baseline strategy that targets the least-cost investment pathway that meets projected loads.

Power sector stakeholders may prioritize certain evaluation metrics in order to assess and prioritize future power system investments—these metrics typically include indicators of cost, reliability, and effectiveness. For example, the performance of different power sector investment strategies can be evaluated against different policy drivers (e.g., increase fuel diversity, greater reliance on indigenous resources, defined emissions constraints, etc.) Some specific metrics might include residential load served, net present value of revenue requirements, and greenhouse gas emissions. Ultimately, power sector stakeholders can evaluate investments that are likely to perform well over a wide range of potential futures, and consider trade-offs of investment choices, to come up with a "least-regrets" resource plan. A "least-regrets" plan is expected to be more resilient to changing circumstances than just a least-cost plan.

The least-regrets resource plan that comes of the IRRP process is expected to be more successful under a variety of future scenarios. Scenarios reflect a set of model inputs (e.g., load forecasts, fuel prices and availability, technology costs and availability, resource availability, and variability under climate change). Alternative scenarios reflecting projected changes in climate, that reflect changing risks and uncertainties, can be considered to understand the sensitivity of different investment strategies to climate change. These alternative scenarios can be compared to a reference scenario, which would reflect the historical (baseline) climate, or likely forward conditions.

Since IRRP looks across the power system, including power supply, transmission, distribution and demand, detailed assessments involving numerical models can be used to assess risks and test the performance of adaptation measures given different climate change and growth scenarios. For example, using the IPM, which is the primary power system model for the IRRP project, one can assess risks and test adaptation measure performance. Increases in temperature and its effects on the efficiency of transmission, distribution, and generation, or on energy demand, can be taken into account in the individual component analysis. The resulting impacts of increases in temperature on the power system performance can be evaluated through application of the IPM model. Demand-side and conservation strategies can also be explicitly considered within the IPM model, in order to evaluate their potential at increasing system resilience.

Similarly, the hydropower potential under different assumptions of climate change could modelled to assess impacts on generation as a result of increases or decreases in precipitation (including extremes, or changes over time). Adaptation measures, including operational changes, or changes in water management could also be considered.[182]

In order to inform the least-regrets resource plan, the chosen evaluation metrics (listed above) are appropriately weighted given stakeholder preferences, and combined to determine a score for each investment strategy. Strategies can be chosen by stakeholders based on their score on each metric.

[182] Under the USAID IRRP Project in Tanzania, the Water Evaluation and Planning System (WEAP) model has been applied to assess impacts and adaptation strategies. WEAP has been applied to assess changes in hydropower in Ghana, but these models would need to be updated, and connected to the IPM model to assess impacts more broadly on power system resilience and planning.

Stakeholders can consider the performance of different investment strategies under different scenarios, in order to identify those strategies that may be more robust under a range of future conditions. The recommended, least-regrets resource plan is one that provides the highest performance under the selected metrics, and will be the basis for the power system master plan.

Finally, since the timing, nature, and magnitude of climate impacts is uncertain and evolves over time, the power system master plan will include an iterative and adaptive management approach. This implies tracking and evaluating performance, monitoring changing conditions, considering new risks and opportunities during and after the adaptation planning and implementation, and updating the IRRP and master plan.

To achieve its ambitious power sector goals, Ghana's energy decision makers must have a clear understanding of the potential climate risks the sector faces, and the types of options and resources available to manage them. Application of an IRRP approach helps to build climate resiliency into power systems planning by explicitly recognizing climate and other risks, as well as their potential impacts to the Ghanaian power sector—allowing for power sector planners to consider and weigh the performance of different investment portfolios to reduce impacts while meeting sector objectives.

# RESOURCES

Below are a number of resources with information on climate change projections, approaches for integrating climate change into the power sector, and climate change in Ghana.

## RESOURCES ON CLIMATE CHANGE PROJECTIONS

| AUTHOR | REPORT | DESCRIPTION |
|---|---|---|
| IPCC | Working Group I's contribution to the IPCC's Fifth Assessment Report | This report presents the latest information on observed climate changes and future climate projections, along with climate mitigation and adaptation information for various sectors, including energy. |

## RESOURCES FOR INTEGRATING CLIMATE CHANGE INTO THE POWER SECTOR

| AUTHOR | REPORT | FOCUS | DESCRIPTION |
|---|---|---|---|
| World Bank | Climate Impacts of Energy Systems: Key Issues for Energy Sector Adaptation | Projected climate change; energy system climate vulnerability; adaptation theory and strategies | This report provides an overview of climate change impacts that might affect the energy sector and what options exist to address the impacts. |
| ADB | Guidelines for Climate Proofing Investment in the Energy Sector | Energy system climate vulnerability; adaptation strategies at the project, policy, and planning levels | This technical note aims to provide guidance to project teams as they integrate climate change adaptation and risk management into each step of project processing, design, and implementation. The note encompasses lessons learned and good practices identified through ADB energy projects. |
| ADB | Climate Risk and Adaptation in the Electric Power Sector | Electric power sector climate vulnerability; Adaptation strategies by generation type and at the policy and planning level | This report discusses the exposure and vulnerability of the energy sector to climate change. It identifies adaptation options available to each source of energy generation as well as for the distribution and end use of electrical energy. |
| IPCC | Special Report on Renewable Energy Sources and Climate Change Mitigation | Renewable energy; climate mitigation | This report includes a discussion on the potential impact of climate change on renewable energy resources. |
| World Bank | Climate & Disaster Risk Screening Tools: Energy Sector | Climate and disaster risk screening tool | Energy project developers evaluate potential impacts of climate change on projects, with modules for: thermal power, hydropower, other renewables, energy efficiency, T&D, and energy capacity building. |
| World Bank | Hands-on Energy Adaptation Toolkit | Vulnerability assessment of energy; adaptation options; cost-benefit analysis; decision making | A stakeholder-based, semi-quantitative risk assessment to prioritize risks to a country's energy sector and identify adaptation options. |

## RESOURCES ON CLIMATE CHANGE IN GHANA

| CREATOR | RESOURCE | OPTIONS | DESCRIPTION |
|---|---|---|---|
| The Nature Conservancy | ClimateWizard | CMIP 3 projections for 28 temperature, precipitation, and aridity variables. Mid- and end-of-century time horizons at an annual and monthly scale. Allows for shapefile uploads and custom polygons. | ClimateWizard enables technical and non-technical audiences alike to access leading climate change information and visualize the impacts anywhere on earth. Information includes historical and predicted temperature and precipitation. |
| The World Bank | Climate Change Knowledge Portal (CCKP) and Country Adaptation and Risk Profiles | CMIP 3 projections for 16 temperature and precipitation variables, and CMIP 5 projections for four variables. Four 20-year time horizon options, starting at 2020, 2040, 2060, and 2080. Data download only available for entire countries and water basins, no custom shapes. | CCKP provides historical and future climate and climate-related datasets, including information on the impacts of climate change to water resources. The profiles serve to synthesize and distill datasets for screening purposes. |
| KNMI | Climate Explorer | Historical climate station data at an annual, monthly, and daily scale. Projected CMIP 3 projections for 16 variables, and projected and hind-casted CMIP 5 data for 53 variables. Allows for custom shapes. | Climate Explorer allows for the download of historical climate station data and projected climate data. |
| UCT CSAG/ UNITAR | Climate Information Platform (CIP) | Historical data on precipitation and temperatures. Projected CMIP 3 data for mid- and end-of-century and projected CMIP 5 data through end-of-century. Data only available for specific stations (oftentimes within major cities). Africa only. | CIP includes observational and projected climate data for African cities. |

# K. RISK AND RESILIENCE WORKSHOP REPORT

In October 2017, the IRRP project held a workshop to discuss the various climate change risks and resilience options for Ghana's power sector. The workshop was participatory to get feedback from stakeholders on the various resilience measures.

The agenda and proceedings of the workshop are provided below.

IRRP Project

# Climate Change Risk and Resilience Workshop

## Training workshop on Climate Change Risk and Resilience in Ghana's Power Sector

USAID/Ghana Integrated Resource and Resilience Planning Project
October 2017

Contents



## Figures and Tables

# 1 Introduction

The Integrated Resource and Resilience Planning (IRRP) project received additional funds from USAID in August to expand the scope and duration of the project. One of the three key areas of the expanded scope is to provide specific support to the Ghana EPA to implement the Ghana Nationally Determined Contributions (GNDC) under the Paris Agreement. Further to this, evaluate climate change impacts and associated resilience measures for the Ghana power sector. To this end, ICF is providing technical assistance and capacity building for MESTI, EPA, NADMO, CSIR, and other climate change stakeholders on various aspects related to achieving Ghana's climate change commitments.

In collaboration with MESTI and EPA, ICF will undertake analytical and capacity building work supporting GHG accounting, verification and monitoring; adaptation and mitigation measures focused on the energy sector; development of proposals for the Green Climate Fund; updating climate models and associated impacts on hydrological modeling; climate impacts on off-grid systems; inclusion of climate change impacts and adaptation measures in the environmental and social impact assessments (ESIA); and other related issues.

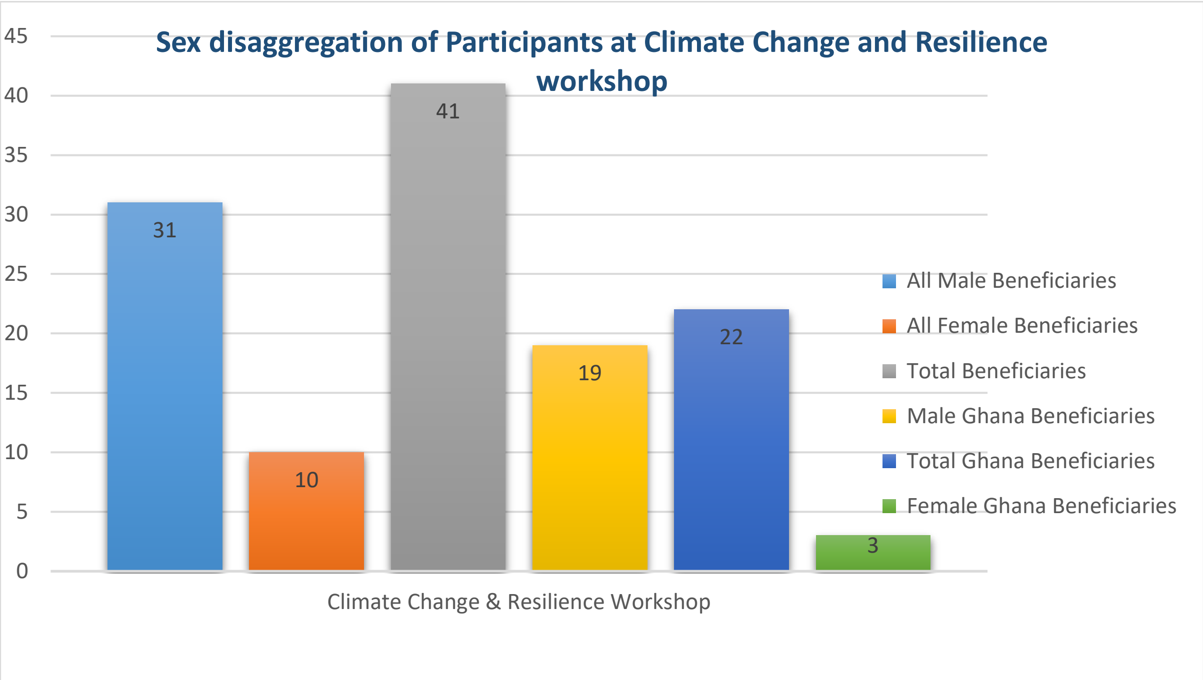
This workshop was used to kick-start the climate activities in the expanded scope. The purpose was to bring all the key stakeholders to one platform, and identify the respective roles and efforts being made regarding climate risks and adaptation in Ghana.

The workshop was held at the La Palm Royal Beach hotel, Accra on October 25, 2017.

## 1.1 Attendance

The workshop was attended by a total of 41 people from the MESTI, EPA, MLGRD, CDIR, NADMO, Forestry Commission, Ecobank, Development Partners, and private entities. The breakdown of the participants is shown in **Figure 1** below.

*Figure 1: Sex disaggregation of participants at the Climate Change and Resilience Workshop*



### *1.2 Opening*

The workshop was called to order at 9:15am by the COP of the IRRP project. He welcomed all to the workshop. Following a brief self-introduction, he made a short presentation on the concept of the IRRP project, current status of implementation, and the objectives of the climate related activities in the work plan of the expanded scope of work. The sequence of proceedings is as shown in the table below. The sequence of the activities at the workshop were as shown in **Table 1** below.

***Table 1: Sequence of Proceedings at the workshop***

| No. | Activity | Facilitator |
|---|---|---|
| 1 | **Presentation 1:** *Climate Risk and Resilience in Ghana incl. NDCs* | Daniel Benefor, Principal Program Officer; EPA |
| | **Presentation 2:** *Mainstreaming Climate Risks in Power Sector* | Kennedy Amankwah, Energy Commission |
| 3 | **Presentation 2:** *Disaster Risk Reduction and Climate Resilience* | Charlotte Norman; Director of Climate Change Adaptation; NADMO |
| 3 | **Risk and Resiliency Report:** *Climate Risks to the Power Sector* | Molly Hellmuth, Senior Technical Specialist, Africa Climate Resilience Lead; ICF |
| 4 | **Small Group Exercise & Presentation:** Identifying and Prioritizing Climate Risks | Molly Hellmuth, Senior Technical Specialist, Africa Climate Resilience Lead; ICF |
| 5 | **Risk and Resiliency Report & Presentation:** Building Climate Resilience into the Power Sector | Molly Hellmuth, Senior Technical Specialist, Africa Climate Resilience Lead; ICF |
| 6 | **Small Group Exercise:** Identifying Adaptation Measures for Priority Climate Risks | Molly Hellmuth, Senior Technical Specialist, Africa Climate Resilience Lead; ICF |

# 2 Key Activities of the Day

The key activities of the day included presentations and the group exercises.

### *2.1 Discussions*

The main discussions in the workshop centred on the presentations and the group exercises. The participants were allowed to ask the presenters several questions relating to the topics presented. In addition to the main presentations, presentations on the output of the group exercises were made, and interrogated by the members of the other groups.

### *2.2 Key Issues Raised During Presentations and Deliberations*

The key issues raised in the presentations on the various topics are indicated in **Table 2** below.

*Table 2: Key Issues raised during the presentations*

| No. | Issue | Response |
|---|---|---|
| ***A.*** | ***Presentation by EPA*** | |
| 1 | What is EPA doing about the sulphur content of our fuel? | ***EPA:*** The GSA, OMCs, TOR, and NPA are working to reduce the sulphur content of the fuel. The current standard is 50ppm but in the future EPA is working towards 10ppm. The 50ppm should have been implemented in August 2017 but it has been put on hold until the end of 2017. |
| 2 | ***IRRP:*** What is the currency of the budgeted 22billion? | ***EPA:*** It is in US dollars |
| 3 | ***JICA:*** Do the relevant Agencies have the capacity to collect accurate data which is disaggregated into the emissions contribution from the various sectors? | ***EPA:*** The EPA relies fully on the energy balance data produced by the EC, which the EC collected from the utilities. |
| 4 | ***IRRP:*** What are the conditional actions that will help achieve the targeted 45% reduction? | ***EPA:*** The conditional actions are extensive and will be shared with the IRRP team in due course. |
| 5 | ***JICA:*** How are the relevant institutions on sectoral contributions to GHG emissions? | ***EPA:*** Data collection is a challenge in this country, nonetheless the EPA collects emission data from the energy balance prepared by the Energy Commission. |
| ***B.*** | ***Presentation by the EC*** | |
| 6 | ***Swiss Embassy:*** It is imperative for the technocrats to sensitize the political leadership on the benefits of the climate mitigation and adaptation, because they are key stakeholders in the implementations of interventions. | |
| 7 | ***EPA:*** There is the need for concerted efforts by all stakeholders to mitigate the risks associated with climate change. The technocrats, politicians, and all other stakeholders should play their respective roles to ensure that the goals and objectives of the climate interventions are realized. | |
| ***C*** | ***Presentation by NADMO*** | |
| 8 | ***IRRP:*** How did NAMDO define "***drought***" in the ARC? | ***NADMO:*** "***Drought***" was defined as about 10days of no rain before the planting season, which essentially means long dry spells |
| 9 | ***ECOBANK:*** What is the medium by which NADMO received the early weather signals from GNET? | ***NADMO:*** It was done via phone call |
| ***D*** | ***Presentation on Findings From the Climate Risk and Resilience Report*** | |

| No. | Issue | Response |
|---|---|---|
| 10 | ***EPA:*** Considering the poor drainage system in Ghana, how can the floods in Accra be attributed to the effects of climate change or otherwise | It is important to recognize the impact of land use and other factors on flooding. One way is to take the difference between exposures and adaptive capacity. The non-climate issues only exacerbate the climatic impacts. It is therefore imperative to recognize the impact of changes in climate to flooding, while addressing the non-climate issues to minimize the effect. |
| 11 | **EPA:** How can modelling be used to minimize the uncertainty in rainfall and other weather patterns? | ***IRRP:*** There will always be uncertainties. However, this can be reduced progressively with the continual acquisition of better data, which will result in better decision making |
| 12 | ***EPA:*** What indicators were used in the analysis, which put Ghana in the top 20 most vulnerable countries to the impact of climate change? | It's a combination of indicators which include, amongst others agriculture as a share of GDP, Adaptive capacity, vulnerability index, exposure sensitivity, etc. |
| 13 | ***Swiss Embassy:*** What is the impact of Geo-engineering the climate change and was it taken into consideration in the climate assessment of Ghana? | ***IRRP:*** This is a deviation from the focus of this workshop so may not be helpful to include that in the discussions here. Again, it was not taken into consideration in the climate risks and assessment report because it is not relevant. |
| 14 | ***IRRP Modeling Consultant:*** Given the significant infrastructural development along the coast, it is acceptable to attribute sea level rise to only climate change? | ***IRRP:*** There is no identified causality between infrastructural development along the sea and sea level rise. |

## *2.3 Exercises at the workshop*

One key aspect of the training workshop was the three group exercises by the participants. These were on:

- **Identifying and Prioritizing Climate Risks**: Small Group Exercise & Presentation
- **: Building Climate Resilience into the Power Sector:** Risk and Resiliency Report & **Presentation**
- **Identifying Adaptation Measures for Priority Climate Risks**: Small Group Exercise

All the exercises were facilitated by the Senior Technical Specialist, Africa Climate Resilience Lead; ICF. The participants were divided into four groups for these exercises. After the deliberations, each group presented a summary of their findings. The results of these presentations are discussed in the next section.

### 2.3.1 *Results of Group Exercises:*

The results of the group exercises were as presented below.

**<u>Historical Climate Risks to Power Systems</u>**

This section summaries the discussions and results from the four groups on this exercise.

<table>
<tr><th>Group No.</th><th>Output</th><th>Trend with climate change</th></tr>
<tr><td rowspan="3">Group 1</td><td><ul><li>Group 1 identified "Extreme rainfall and flooding on hydro" as Priority 1 in terms of historical risk to power in Ghana. The reason being that, high levels of rainfall will affect the water levels of the dam, which under extreme cases, spilling might not be enough to curtail the potential damage. The floods could also affect the switchyard infrastructure which are located downstream.<br>Extreme rainfall and flooding also affect thermal generation plants as well as substations and other transmission and distribution infrastructure. It could also result in damage to renewable energy infrastructure. During periods of extreme rainfall and flooding, demand for electricity may reduce.</li></ul></td><td><ul><li>Effects of Extreme rainfall and flooding on:<ul><li>hydro will worsen;</li><li>Thermal generation could worsen or improve</li><li>Renewables will worsen</li><li>T&D will worsen</li><li>Demand will improve</li></ul></li></ul></td></tr>
<tr><td><ul><li>The second priority area for Group 1 was the effect of "Temperature on Transmission and Distribution". With long periods of high temperature, transmission and distribution lines expand leading to high transmission and distribution losses. The lines also sag more. Aside from this, high temperatures also cause evapotranspiration, which results in a reduced amount of water in water sources. High temperature also means more effort needed to cool thermal plants, thereby affecting the efficiency of the equipment. High temperatures also reduce the efficiency of solar PVs and also shortens the lifespan of the batteries. It also negatively affects the growth of biomass. In high temperatures, demand for electricity increases.</li></ul></td><td><ul><li>Effect of "Temperature" on:<ul><li>Hydro will worsen</li><li>Thermal generation will worsen</li><li>Renewables will worsen</li><li>T&D will worsen</li><li>Demand will worsen</li></ul></li></ul></td></tr>
<tr><td><ul><li>Third priority was the effect of "drought on hydro". This is because electricity generation is reduced as a result of low inflows into the dam. This also results in the cavitation of the runners and damage to the blades. Further, drought will increase the competition for water for cooling of thermal plants. It will also result in accumulation</li></ul></td><td><ul><li>Effect of "drought" on:<ul><li>Hydro could worsen or improve</li></ul></li></ul></td></tr>
</table>

| Group No. | Output | Trend with climate change |
|---|---|---|
| | of dust on solar PVs and also impedes the growth of biomass. Drought also results in suppressed demand.<br><br>• The fourth priority here was "***temperature on thermal***". This is because the efficiency of plants is affected when the temperature of the atmospheric air increases. | |
| ***Group 2*** | • The first priority of this group was the effect of "***drought on hydro***". This is because of potential decreased generation due to low availability of water, coupled with increased competition for limited water resources.<br><br>The drought conditions will also result in decreased bioenergy generation, potential bush fires could also damage transmission and distribution lines.<br><br>• The second priority is the effect of ***temperature on demand***. Extended periods of sustained high temperatures will result in increased demand for power for cooling.<br><br>• The third priority was ***extreme rainfall and flooding on Transmission & Distribution***. This is because extreme rainfall will cause erosion of transmission pylons. A classic example is when extreme flooding in Northern Ghana in 1998 caused distribution poles to tilt. Another case of flooding at Ofankor caused damage to the substation and resulted in interruption in supplies. Extreme rainfall also poses risks to the dam. An example is when the Akosombo dam spilled in November 2010 and in 1992.<br><br>• The fourth priority is the ***water flow, volume, and timing on hydro***. Here, inflows into the dam will be affected and this has a consequential effect on the amount power produced. It will also result in a shift in the operational rules of the hydro facility. | • Effect of ***"drought"*** on:<br><br>• Effect of temperature on:<br>o Hydro will improve<br>o Thermal generation will worsen<br>o Renewables will worsen<br>o T&D will worsen<br>o Demand will worsen<br><br>• Effect ***of water flow, volume, and timing*** on hydro will worsen |

<table>
<tr><th>Group No.</th><th>Output</th><th>Trend with climate change</th></tr>
<tr><td>Group 3</td><td><ul><li>The first priority is Temperature on Demand. Demand increases with increase in temperature Temperature also causes evaporation in water bodies, decreases the efficiency of thermal plants due to increased temperature of the water used in the cooling. High temperatures may also increase the pressure of fuels used in thermal generation. On the other hand, high temperatures can improve the energy generated by solar PVs. High temperatures can also decrease the capacity and lifespan of transmission infrastructure. High temperatures result in increased demand.</li><li>The second priority is drought on hydro. Here increased drought results in reduction in hydro potential, reduce the amount of water available for cooling.</li><li>The third priority is extreme rainfall, largely because it leads to spillage of dams, increased cloud cover due to rainfall, which decreases the amount of energy generated by solar PVs, causes damage to T&D infrastructure – NEDCO lost a 100 poles in 2016 to extreme rainfall.</li></ul></td><td><ul><li>Effect of temperature on:<ul><li>Hydro could worsen or improve</li><li>Thermal generation will worsen</li><li>Renewables will worsen</li><li>T&D will worsen</li><li>Demand will worsen</li></ul></li></ul></td></tr>
<tr><td>Group 4</td><td><ul><li>The first priority is drought on hydro. The reason being that drought will affect water level and availability.<br>Drought will also result in less water available for cooling of thermal plants.</li><li>The second priority is drought on T&D.</li><li>The third priority is Extreme rainfall on T&D. Extreme rainfall causes sedimentation of dams. It also causes outages due to power lines falling down and flooding o substations.</li><li>The fourth is Temperature on demand. Extreme temperature will affect water levels due to evaporation. It also affects the efficiency of power plants, and causes power lines to sag.</li></ul></td><td></td></tr>
</table>

## Selecting Resilience Measures

The four groups were assigned climate stressors to identify potential residence measures based on policies & plans, technologies, operations and Maintenance, and Structural. The results of this exercise are as indicated in **Table 5** in Appendix C. The four climate stressors assigned to the groups were:

i. Water flow volume and timing on hydropower;
ii. Extreme rainfall and flooding on Transmission and Distribution;
iii. Drought and high temperature on Transmission and Distribution; and
iv. Drought on hydropower.

The discussions on these four climate stressors are indicated below:

***Table 3: Resilience Measures Discussed by the four groups***

| Policies and Plans | Technologies | Operations and Maintenance | Structural |
|---|---|---|---|
| 1. Water flow volume and timing of hydropower | | | |
| **Measure:**<br>Depends on the meteorological services to aid in forecasting. Adopt an integrated forecast plan (Water Flow Volume)<br><br>**Advantages**:<br>Reduced uncertainty<br><br>**Barriers:**<br>Adequate capacity | **Measure:**<br>- Gauging of weather stations<br>- Modelling tools<br><br>**Advantages:**<br>- Real time values for inflows<br>- Modelling helps in planning for generation<br>- Cost/capacity | **Measure:**<br>- Proper care given to measuring instruments from gauging and weathering stations<br>- Data verification<br><br>**Advantages/Barriers:**<br>- Keeps the system fully functional<br>- Operation builds confidence in the system<br>- Cost/proper operation and maintenance ethics | |
| **2. Extreme rainfall and flooding on Transmission and distribution** | | | |
| **Measure:**<br>Institution of policies and plans to map out high prone areas to guide the siting of T&D facilities | **Measure:**<br><br>Early automated warning systems<br><br>Auto-restoration of infrastructure after rainfall or flooding | **Measure:**<br>Proper drainage maintenance and clearing of environs of T&D infrastructure in rainy season | **Measure:**<br>- Elevation and relocation of existing infrastructure<br>- Replacement of wooden |

| Policies and Plans | Technologies | Operations and Maintenance | Structural |
|---|---|---|---|
| **Advantages:**<br>Feasible/Effective | | **Advantages**: Cost effective | distribution poles |
| 3. **Drought and high temperature on Transmission and Distribution** | | | |
| ***Measure:***<br>Awareness of effect of bush fires on T&D lines | ***Measure****:*<br>- Research into power resistant poles<br>- Using of a cooling technology on T&D lines<br>- Introduce early waving signs to detect fires | ***Measure****:*<br>- Regular monitoring of T&D lines<br>- Create fire corridors around T&D lines | ***Measure:***<br>Introduce fire resistant materials on T&D poles |
| ***Advantages:***<br>Resilience measure through knowledge increase<br>***Barriers:***<br>Lack of commitment | ***Advantages:***<br>- Security in the face of PV<br>- Protective measure<br><br>***Barriers:***<br>Lack of funding/feasibility | ***Advantages:***<br>- Preventive measures<br>- Proactive<br>- Updated information on T&D lines<br><br>***Barriers:***<br>Lack of labour and cost | ***Advantages:***<br>Security is needed<br><br>***Barriers:***<br>Feasibility and cost are inadequate |
| 4. **Drought on hydropower** | | | |
| ***Measure:***<br>Hydro/solar complementation<br><br>***Barriers:***<br>Difficulty in land acquisition | ***Measure:***<br>Solar PV installation<br>Solar PV with storage | ***Measure:***<br>- Day-time reduction of hydro power through generation from the solar PVs<br>- Frequent cleaning of the solar panels | ***Measure:***<br>The panels should be elevated to prevent flooding |

# APPENDIX A

***Table 4: Participants of the Climate and Resilience workshop***

| No. | Name | Institution | Position |
|---|---|---|---|
| 1 | Sulemana  Abubakari | MoEn | Deputy Director, Materials |
| 2 | William Sam-Appiah | MoEn | Director Power Generation |
| 3 | Godfred Ofosu-Asare | VRA | Environmental Officer |
| 4 | Salifu Wumbilla | BPA | Manager, Resource & environment |
| 5 | Keli Sekor | BPA | Assistant Mechanic Officer |
| 6 | Tampuri Tayeb | NEDCo | Planning Engineer |
| 7 | Salifu Addo | Energy Commission | Principal Program Officer Energy Stats |
| 8 | Kennedy Amankwa | Energy Commission | CPO |
| 9 | Daniel Benefoh | Energy Commission | Program Officer, Strategic Planning and Policy |
| 10 | Simpson Attieku | EPA | PPO |
| 11 | Kyekyeku Oppong-Boadi | EPA | Director |
| 12 | Jerry Asumbie | EPA | P.O |
| 13 | Bente Avah | EPA | National Service Person |
| 14 | Isaac Danso | EPA | National Service Person |
| 15 | Antwi-B Amoah | EPA | PPO |
| 16 | Barnabas Amisigo | CSIR-WRI | Snr Research Scientist |
| 17 | Isaiah Nimako | KITE | Project Officer |
| 18 | James Otoo | NADMO | SOCO |
| 19 | Charlotte Norman | NADMO | Director |
| 20 | Eric Afornorpe | MoLGRD | Assistant Director |
| 21 | Gifty Owusu-Nhyira | Ecobank | Project Monitoring Officer |
| 22 | Charles Dvah S. | Forestry Commission | Manager |
| 23 | Timothy Twerefour | ICF/IRRP | M&E Assist |
| 24 | Waqar Haider | USAID | Senior Energy Advisor |

| No. | Name | Institution | Position |
|---|---|---|---|
| 25 | Charles Acquaah | ICF/IRRP | M&E CB Specialist |
| 26 | Seth Adjei Boye | Swiss Embassy | Information Specialist |
| 27 | Maxwell Amoah | ICF/IRRP | Deputy Chief of Party |
| 28 | Maame T. Ankoh | ICF/IRRP | RE Specialist |
| 29 | Joshua B. Mabe | JICA | Program Officer Strategic Planning and Policy |
| 30 | Molly Hellmuth | ICF/IRRP | Hydropower and Climate Risk Expert |
| 31 | Edith Mills Tay | ICF/IRRP | Office Manager |
| 32 | Bernard Modey Tawia | ICF/IRRP | Senior Power Expert |
| 33 | Dorothe Yong Nje | United Nations University | Research Fellow |
| 34 | Abdul-Razak Saeed | ICF/IRRP | Climate Resilience Specialist |
| 35 | Mark Summerton | ICF/IRRP | Senior Climate Expert |
| 36 | Karen Bel | US Embassy | R.E.O |
| 37 | Mariam Fuseini | ICF/IRRP | Climate Capacity Building Coordinator |
| 38 | Melissa Knight | USDA | PARP COP |
| 39 | Ananth Chikkatur | ICF/IRRP | Chief of Party |
| 40 | Collins Dadzie | ICF/IRRP | Energy Modeler |
| 41 | Mawunyo Dzobo | ICF/IRRP | Consultant |

## APPENDIX B

### Climate Risks to the Power Sector

**Pre-Training Exercise:** What are the historical climate risks to the power system?

***Table 5: Historical Risk to Power Sector***

<table>
<tr><th rowspan="2">Climate Stressor</th><th colspan="3">Generation</th><th rowspan="2">Transmission & Distribution</th><th rowspan="2">Demand</th></tr>
<tr><th>Hydro</th><th>Thermal</th><th>Renewables</th></tr>
<tr><td colspan="6">Group 1:<br>Priority 1: Extreme rainfall – Hydro Priority 2: Temperature – Transmission & Distribution<br>Priority 3: Drought – Hydro Priority 4: Temperature – Thermal</td></tr>
<tr><td>Extreme Rainfall & Flooding</td><td>• High levels leads to spills which affects the stability of the dam. Certain levels must not be exceeded otherwise extreme rain can damage dam infrastructure<br>• Switch yard infrastructure downstream affected (+)<br>• Settlement sedimentation downstream<br>• Farms e. Banana farms get flooded</td><td>• Substation infrastructure flooding damage<br>• Service delivery disruptions<br>• Limited access to plants<br>• Increased output (+) / (-)</td><td>• Infrastructural damage<br>• Reduces power generation reliability (+)</td><td>• Infrastructural damage<br>• Increases maintenance costs<br>• Service disruption (+)</td><td>• Peak demand may reduce (-)</td></tr>
<tr><td>Temperature</td><td>• Water resource amount reduced due to evapotranspiration increase<br>• Affects cooling of equipment (+)</td><td>• Efficiency of plants are affected when temperature of air is higher (+)</td><td>• PV efficiency or output is reduced<br>• Battery lifespan is reduced</td><td>• More expansion of transmission lines which leads to losses<br>• Lines sag more (+)</td><td>Demand for energy rises (+)</td></tr>
</table>

| Climate Stressor | Generation | | | Transmission & Distribution | Demand |
|---|---|---|---|---|---|
| | Hydro | Thermal | Renewables | | |
| | | | • Affects growth of biomass sources (+) | | |
| **Drought** | • Output reduces<br>• Cavitation of the runners and damage to the blades<br>• Infrastructure (+)/(-) | More water resources needed for cooling if using freshwater then output will reduce because cooling would not be possible | • Dust accumulation on panels that affects output<br>• Reduction in biomass feed | • Bush fires<br>• Electrical poles burning<br>• Transmission lines sag | • Suppressed demand |
| **Water Flow, Volume and Timing** | High water flow will have an impact on dam infrastructure<br>Increase in production<br>Low water will reduce output (-) | | | | |
| **Sea Level Rise & Storm Surge** | N/A | Infrastructure damage<br>station floods<br>sedimentation | | | |
| **Group 2:**<br>**Priority 1: Drought– Hydro**<br>**Priority 2: Temperature – Demand**<br>**Priority 3: Extreme Rainfall – Transmission & Distribution**<br>**Priority 4: Water flow, Volume & Timing – Hydro** | | | | | |
| **Extreme Rainfall & Flooding** | • Risk of damage to the dam e.g. Akosombo was spilled in November 2010 and 1992 | | | • Erosion of transmission pylons | Demand for electricity |

| Climate Stressor | Generation | | | Transmission & Distribution | Demand |
|---|---|---|---|---|---|
| | Hydro | Thermal | Renewables | | |
| | (+) | | | • Major floods in the north caused the tilting of a distribution pole in 1998<br>• Flooding at Ofankor substation (+) | |
| **Temperature** | Reduces water levels and causes low generation<br>(-) | Increase temperature impact on the efficiency and cooling system of the plant<br>(+) | Impact on the efficiency and effectiveness of the renewables like battery. E.g. High temperature leads to lower lifespan of the battery<br>(+) | Substation will be affected in terms of expansion and over-heating (+) | Increased demand for power for cooling<br>(+) |
| **Drought** | Decreased generation due to low availability of water and increased consumption of water as a result of competing users (-) | | Affects bio-energy generation | Bush fires | Increase demand for rain harvest technology |
| **Water Flow, Volume and Timing** | • Levels of power production (+)<br>• Shifts in operational rules of facilities | | | | |
| **Sea Level Rise & Storm Surge** | | Flooding of coastal installations | | | |
| **Group 3:**<br>**Priority 1: Temperature – Demand** | | | **Priority 2: Drought – Hydro** | | |

| Climate Stressor | Generation | | | Transmission & Distribution | Demand |
|---|---|---|---|---|---|
| | Hydro | Thermal | Renewables | | |
| **Priority 3: Extreme Rainfall** | | | | | |
| **Extreme Rainfall & Flooding** | Leads to spillage (+)/(-) | N/A | Increased cloud cover due to rainfall which decreases kwh output(-) | Damage to infrastructure e.g. T&D lines, 100 poles lost in 2016 in NEDCo (-) | Low Demand due to low temperatures (-) |
| **Temperature** | High temperatures causes evaporation in water bodies (+) | • Decreased efficiency due to increased temperature in water for cooling<br>• High temperatures may improve fuel pressure<br>(+) | May improve kwh solar panels (+) | • Decrease in transmission capacity<br>• Decrease in equipment life span<br>(+) | Increase demand (+) |
| **Drought** | Reduction in hydro potential | Reduce water for cooling | Impact on small lighter plants | N/A | Increase in demand in irrigation/pumping |
| **Water Flow, Volume and Timing** | Erratic flow of water | Decrease in plant efficiency due to water shortage | RE impact on small hydro | N/A | |
| **Sea Level Rise & Storm Surge** | N/A | Infrastructure damage along the coast | Infrastructure damage | Damage to T&D lines | |
| **Group 4:**<br>**Priority 1: Drought – Hydro** **Priority 2: Drought – Transmission & Distribution**<br>**Priority 3: Extreme rainfall –Transmission & Distribution** **Priority 4: Temperature – Demand** | | | | | |

| Climate Stressor | Generation | | | Transmission & Distribution | Demand |
|---|---|---|---|---|---|
| | Hydro | Thermal | Renewables | | |
| **Extreme Rainfall & Flooding** | • Sedimentation (+)<br>• Capacity of dams(-) | • Production (-)<br>• Humidity (+)<br>• Air filters (-) | N/A | • Outages and dropping of power lines<br>• Flooding of substations | Reduces demand |
| **Temperature** | • Evaporation (+)<br>• Water level (-) | • Efficiency in production (-)<br>• Air density(-) | | • Sagging of power lines(-) | Demand on cooling(+) |
| **Drought** | Water level & available capacity (-) | Water intake(-) | | Distribution lines | Cooling (+)<br>Reconnection (-) |
| **Water Flow, Volume and Timing** | Spillage (+)<br>Generation(+) | | | | |
| **Sea Level Rise & Storm Surge** | | | | | |

**Key:** **(+)** = worsens with climate change; **(-)** = improve with climate change; **(+) (-)** = could worsen or improve

## APPENDIX C

### Exercise: Selecting Resilience Measures

*Table 6: Resilience Measures for Climate Stressors*

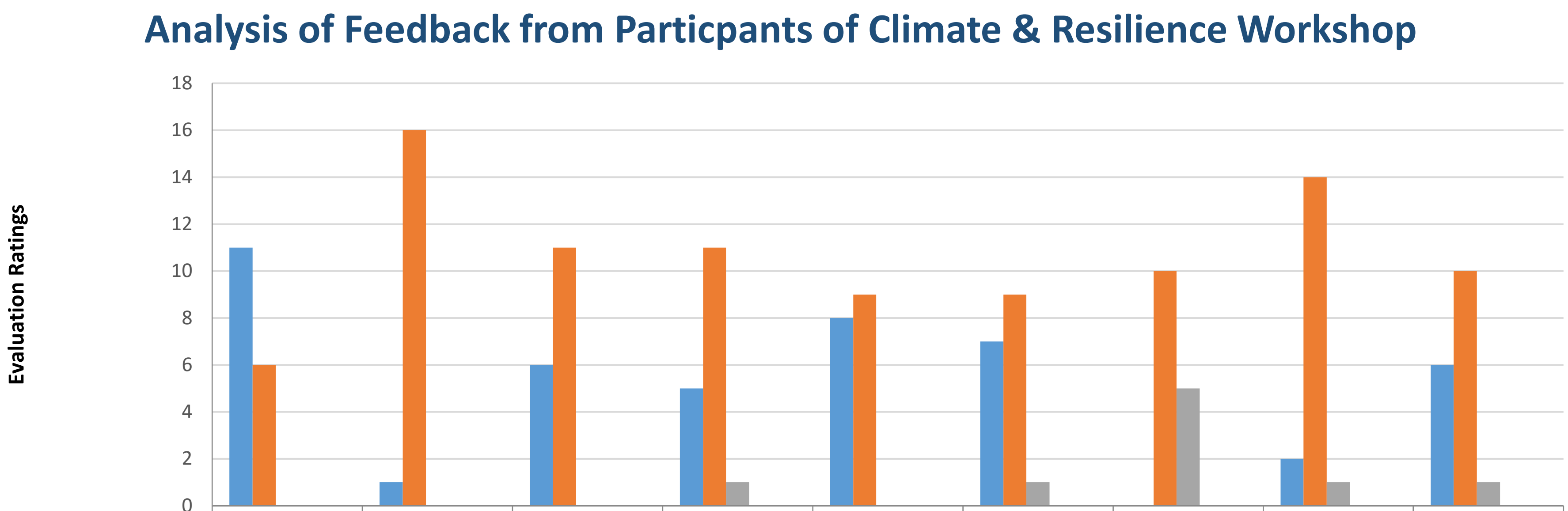
| Policies & Plans | Technologies | Operations & Maintenance | Structural |
|---|---|---|---|
| **Group 1:** Water flow volume and timing of hydropower | | | |
| **Measure:**<br>Depends on the meteorological services to aid in forecasting.<br>Adopt an integrated forecast plan (Water Flow Volume)<br><br>**Advantages**:<br>Reduced uncertainty<br><br>**Barriers:**<br>Adequate capacity | **Measure:**<br>- Gauging of weather stations<br>- Modelling tools<br><br>**Advantages:**<br>- Real time values for inflows<br>- Modelling helps in planning for generation<br>- Cost/capacity<br><br>**Barriers:** | **Measure:**<br>- Proper care given to measuring instruments from gauging and weathering stations<br>- Data verification<br><br>**Advantages/Barriers:**<br>- Keeps the system fully functional<br>- Operation builds confidence in the system<br>- Cost/proper operation and maintenance ethics | **Measure:**<br><br>**Advantages/Barrier**: |
| **Group 2:** Extreme rainfall and flooding on Transmission and distribution | | | |
| **Measure:**<br>Institution of policies and plans to map out high prone areas to guide the siting of T&D facilities<br><br>**Advantages/Barriers:** | **Measure:**<br><br>Early automated warning systems<br><br>Auto-restoration of infrastructure after rainfall or flooding<br><br>**Advantages/Barriers:** | **Measure:**<br>Proper drainage maintenance and clearing of environs of T&D infrastructure in rainy season<br><br>**Advantages/Barriers**: Cost effective | **Measure:**<br>- Elevation and relocation of existing infrastructure<br>- Replacement of wooden |

| Policies & Plans | Technologies | Operations & Maintenance | Structural |
|---|---|---|---|
| Feasible/Effective | | | distribution poles<br><br>**Advantages/Barriers:** |
| **Group 3: Drought and high temperature on Transmission and Distribution** | | | |
| **Measure:**<br>Awareness on effect of bush fires on T&D lines<br><br>Advantages/Barriers:<br>Resilience measure through knowledge increase<br><br>Lack of commitment | **Measure**:<br>- Research into power resistant poles<br>- Using of a cooling technology on T&D lines<br>- Introduce early waving signs to detect fires<br><br>**Advantages/Barriers:**<br>- Security in the face of PV<br>- Protective measure<br><br>Lack of funding/feasibility | **Measure**:<br>- Regular monitoring of T&D lines<br>- Create fire corridors around T&D lines<br><br>**Advantages/Barriers:**<br>- Preventive measure<br>- Proactive<br>- Updated information on T&D lines<br><br>Lack of labour and cost | **Measure:**<br>Introduce fire resistant materials on T&D poles<br><br>**Advantages/Barriers:**<br>Security is needed<br><br>Feasibility and cost are inadequate |
| **Group 4: Drought on hydropower** | | | |
| **Measure:**<br>Hydro solar complementation<br><br>**Advantages/Barriers:**<br>Difficulty in land acquisition | **Measure:**<br>Solar PV installation<br>Solar PV with storage<br><br>**Advantages/Barriers:** | **Measure:**<br>- Day-time reduction of hydro power through generation from the solar PVs<br>- Frequent cleaning of the solar panels<br><br>**Advantages/Barriers:** | **Measure:**<br>The panels should be elevated to prevent flooding<br><br>**Advantages/Barriers:** |

## APPENDIX D

**Evaluation of Workshop**

*Figure 2: Analysis of feedback from Participants of Climate and Resilience workshop*




| | The workshop objectives were clealy spelt out | The workshop lived up to my expectations | The content was relevant to my job | The workshop was easy to follow and understand | The facilitators were well prepared | The facilitators had adequate knowledge of the subjects | The facilitators were able to answer all my questions | The objectives of the workshop were met | All the topics presented were relevant and informative |
|---|---|---|---|---|---|---|---|---|---|
| Strongly Agree | 11 | 1 | 6 | 5 | 8 | 7 | 0 | 2 | 6 |
| Agree | 6 | 16 | 11 | 11 | 9 | 9 | 10 | 14 | 10 |
| Neutral | 0 | 0 | 0 | 1 | 0 | 1 | 5 | 1 | 1 |
| Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Strongly Disagree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX E: Comments from participants

***Table 7: Comments from Participants of Climate and Resilience workshop***

| I benefitted the most from | I benefitted least from | What other topics would you recommend for future workshops | Any other comments |
|---|---|---|---|
| Group Exercises | Technical terms in climate change | Implementation of climate change policies | N/A |
| Climate risk and resilience in Ghana | N/A | N/A | Educative and informative workshop but the next one should be more interactive |
| Proposed climate risk and resilience measures discussed during the group exercises | N/A | N/A | Availability of workshop presentation to all participants |
| Risk and resilience of power systems to climate change impacts and the systematic manner to identify and answer them | N/A | Scenario planning for sustainable power | MESTI should have been present or represented at the workshop |
| Discussions and mapping out strategies to help adapt climate change | N/A | N/A | N/A |
| Presentation on adaptation and resilience of the power sector to climate change and the group exercise | N/A | Elaboration of climate change topics | N/A |
| Group Exercises | Disaster risk reduction and climate resilience presented by NADMO | N/A | Participants interest in the workshop was not sustained |
| Presentation from EC on mainstreaming climate risks in power sector. And EPA for enlightening on how climate change is linked with SDGs | Disaster risk reduction and climate resilience presented by NADMO | N/A | N/A |
| Group Exercises and risk & resilience report on Ghana | N/A | N/A | Political leadership should be presented at such workshops to know the impact of their actions on the environment and nation |

| I benefitted the most from | I benefitted least from | What other topics would you recommend for future workshops | Any other comments |
|---|---|---|---|
| N/A | N/A | N/A | N/A |
| Risk and resilience report on Ghana - Climate risks to the power sector - Building climate resilience into the power sector | N/A | Cost/Benefit analysis of the adaptation options and criteria for prioritization of adaptation options | N/A |
| Group Exercises | N/A | N/A | N/A |
| Group Exercises | N/A | N/A | N/A |
| Group Exercises | N/A | N/A | N/A |
| Risk determination and resilience | N/A | N/A | N/A |
| Presentation on risk and resiliency report- climate risk to the power sector and identifying and prioritizing climate risks with regards to climate stressors | N/A | N/A | N/A |