# ELECTRICITY PLANNING IN WEST AFRICA: WHICH WAY FORWARD?

# AN ADAPTIVE MANAGEMENT PERSPECTIVE ON ENERGY POLICY

A Dissertation
Presented to
The Academic Faculty

by

Ogundiran Soumonni

In Partial Fulfillment

Of the Requirements for the Degree

Doctor of Philosophy in Public Policy

Georgia Institute of Technology

August 2013

ELECTRICITY PLANNING IN WEST AFRICA: WHICH WAY FORWARD?

AN ADAPTIVE MANAGEMENT PERSPECTIVE ON ENERGY POLICY

Approved by:

Dr. Susan Cozzens, Chair
School of Public Policy
*Georgia Institute of Technology*

Dr. Adjo Amekudzi
School of Civil and Environmental Engineering
*Georgia Institute of Technology*

Dr. Marilyn Brown
School of Public Policy
*Georgia Institute of Technology*

Dr. Bryan Norton
School of Public Policy
*Georgia Institute of Technology*

Dr. Valerie Thomas
School of Industrial and Systems Engineering, and
School of Public Policy
*Georgia Institute of Technology*

Date Approved: May 16, 2013

To my parents,

Maria and Elisée Soumonni

## ACKNOWLEDGEMENTS

I would like to thank my committee members for helping me shape this project in each of their own distinct ways from the proposal stage up to this point. In particular, I am grateful to my advisor, Professor Susan Cozzens, for encouraging me to work on an issue that highly motivated me, and for consistently challenging me to remain analytically rigorous throughout the writing of my doctoral dissertation. I am grateful to Professor Marilyn Brown for the opportunity to work within her research group in the Climate and Energy Policy Laboratory (CEPL) for a year, during which I developed a valuable set of skills and greater confidence in energy policy analysis. My thanks are also due to Professor Amekudzi, Professor Thomas and Professor Norton for providing very insightful suggestions, critiques and comments that significantly enriched the scope and depth of this work.

The many long discussions that I had with my friends and colleagues at the Technology Policy and Assessment Center (TPAC) over the years were emblematic of the vibrant intellectual atmosphere within the center, and I am pleased to have been a part of it. In particular, I would like to thank Dhanaraj Thakur for inspiring me to present my work more often at international fora and for always engaging my ideas, while providing practical guidance as to how to investigate them more thoroughly. My thanks go to Ravtosh Bal for being an open, yet critical thinker and friend, to Rodrigo Cortes for sharing his views, ideas and personal challenges openly with me, and to Thema Monroe-White for being like a sister to me during the course of the program. I would also like to thank Anupit Supnithadnaporn for her quiet confidence in me and her encouragement during my first year in the program. Although he had graduated by the time I entered the

doctoral program, my thanks go to Kamau Bobb, whose calm and collected demeanor at occasional TPAC gatherings motivated me to look up his doctoral dissertation, which turned out to be one of the most inspiring dissertations I have ever read, and that I leaned on in so many ways, as a guide for my own work.

My friends and colleagues in the School of Public Policy were also great people to have interacted with and who helped me grow more than they may realize. In particular, I would like to thank You-Na Lee, Rafael Castillo, Johnnie Sawyer, Xiaojing Sun, Hsin-i Huang, Vrishali Subramanian, Heather Smith and Kelechi Uzochukwu for their constant interest in my progress and for always being willing to lend a hand in any way they could. Across the Georgia Tech campus, the friends I would like to thank for their support and some of whom were always sharing information they thought might be relevant to my work include Camellia Henry, Akibi Archer, Christian Braneon, Lateef Yusuf, Tammy McCoy, Zakiya Seymour, Adaora Okwo and Victor Chukwuka. I would also like to thank Soheil Shayegh for orienting me around a number of different energy modeling software packages and helping to double-check my analyses, and Alyse Taylor for telling me as much as I could absorb about her research on the design of smart microgrids. Friends off-campus, near and far, that I am also grateful to for their constant encouragement include Joseph Tarwoe, Akhu Kamau Yaw, Nana Darko Cobinna, Anubhav Jain, Christian Atinyo, Anthony Colon, Satta Massaquoi, Adeseye Sharomi, Sharon Owino, Jerry Johnson, Ousmane Diallo, Desiree Sehlapelo, Segun Odukoya, Nsikan Udoyen, Donald Haase, Abdul Salau, Segun Ladipo and Dele Ladipo.

I am grateful to all my interviewees, and vitally, to those who facilitated the interviews - a process that appeared to be serendipitous in many instances. In this regard,

I would first like to honor the memory and the outstanding scholarly legacy of the late Professor Abeeku Brew-Hammond, who until his recent passing, was the director of The Energy Center (TEC) at the Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, Ghana. Although I never met him in person, he facilitated my interview with one of his colleagues in Accra, based on a simple introduction by a friend of Professor Adjo Amekudzi's. I am also thankful to Lori Pottinger of the International Rivers Network, who first contacted me about my work and then connected me with her associates in West Africa, to Samba Jarju, who put me in touch with officials at the West African Power Pool, and to Banji Oladeji, who connected me with an interviewee in Nigeria and sent me many useful documents on Nigeria's national energy policy.

Last, but not least, is my family, without whose backing, I could not have completed this project. My infinite gratitude goes to my mother, Maria Soumonni, my father, Elisée Soumonni, my sister, Omolola Soumonni, and my aunts, Valentina Mozia and Julie Obi. In different ways, they went through every step of the process with me and were always there to provide emotional, psychological, strategic, and even financial support, whenever I needed it.

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# SUMMARY

Africa's quest for economic development will require the increased availability and use of its abundant energy resources. Nevertheless, most of its rural population remains without access to modern energy services and urban residents typically only enjoy an intermittent supply of electricity. The dominant approach to energy planning in West Africa is top-down and centralized, emphasizing electricity generation from large dams or fossil-fueled plants and subsequent grid extension to reach more customers. However, an alternative and complementary paradigm is that of decentralized or Distributed Generation (DG), which stresses small-scale, on-site generation of power and offers a bottom-up approach to energy development.

The goal of this dissertation project is to assess the various options for regional electrification and integration through a holistic analysis of the set of existing technologies and policies for deploying them. The main organ of the Economic Community of West African States (ECOWAS) for regional electricity planning is the West African Power Pool (WAPP) and its primary policy document, the "Master Plan", addresses regional power supply shortage through centralized planning. Both the WAPP policy documents and the majority of the country-level planning documents are considered to be based on a traditional, empiricist, policy analysis that appears to provide value-neutral solutions and generalizations. In contrast, the analysis provided in this project situates itself within the post-positivistic, deliberative and more contextual approach to policy analysis in order to compare the centralized approach to generation with a distributed approach, which is currently marginal in the region. It uses the Adaptive Management (AM) framework for this analysis, particularly because of the way it deals with ecological resilience in the face of widespread uncertainty.

The main policy issue that this project seeks to address is the need for an integrated energy-environment planning process, which is currently lacking in West Africa, so as to achieve long term sustainability. Adaptive management offers policy makers a holistic lens with which to view energy policy, but there are very few examples of institutions that have attempted to implement it in practice anywhere in the world. These instances, however, represent a valuable historical reference point for future policy research and management efforts that seek to explore this approach. In alignment with that objective, this dissertation first provides an overview of the concept of adaptive management in general, and its application to energy problems in particular.

Secondly, the research project undertakes a policy analysis of the ECOWAS strategy for electrification, based on a stakeholder analysis, a review of life cycle assessments of existing energy technologies, the expected outcomes of the electricity sector, and a set of traditional criteria for evaluating public policies. In order to further examine the question of electricity access, it carries out a quantitative analysis of the electricity demand and supply in the region. It uses a modeling approach that is based on the logic of AM to determine whether or not the energy requirements for broad based electrification can be met through distributed renewable power, which is currently a negligible component of the generation resource portfolio in West Africa.

The dissertation proceeds to carry out a retrospective analysis of three cases in the U.S. where elements of AM have already been applied to energy planning in order to investigate some of the critical determinants for its successful implementation to date. This assessment then informs a prospective analysis of three West African cases that have ideal characteristics for experimentation with AM to determine to what extent similar concepts have been used, or may be employed in the future. The AM framework also calls for the consideration of local values, which should be open to revision in the face of real situations. To this end, the prospective analysis includes three additional place-sensitive criteria, so as to ensure that the framework remains viable in a different socio-political context. The AM analyses are then extended to include a discussion of learning and innovation in clean energy technologies, drawing from the Chinese, Danish and South African experiences.

The results suggest that a strong and consistent political will that is in alignment with an explicit social policy is needed to initiate and implement broad-based electrification plans, but that stakeholder participation is critical to their success. In addition, the adoption of multiple instruments and the selection of a diverse range of energy resources were found to be more effective than an overreliance on a single dominant scheme so as to allow room for policy learning. Furthermore, the results confirm that a holistic approach to managing ecosystems associated with electric power production is a fruitful way to integrate ecological considerations with social and economic factors throughout the development of a project. This type of systemic methodology should also include the building of technological capability and the development of innovation capacity in order to address the unique socio-economic context and the rapidly-changing climatic conditions in West Africa. Finally, the articulation of a planning philosophy that engages the values and sensibilities of the people in a particular place, and that is rooted in them, was found to be a critical factor for increasing the level of public participation in management activities in order to achieve more equitable and democratic outcomes.

# Chapter One

# INTRODUCTION

## 1.1 The Problem and the Argument

The goals of economic and technological development across the world continue to depend on the increasing use of energy resources with fossil fuels being predominant in this energy matrix. However, there is now a well-established link between the processes of industrialization and urbanization and changes in the climate and environment. Balancing this reality with the need for growth and development has spurred considerable thinking about the concept of "sustainable development" at least since the publication of the Bruntland report entitled "Our Common Future" in 1987, which also popularized the term "Global Warming".

Like most other non-industrialized regions of the world, the focus in West Africa has been on economic growth rather than climate change even though in recent years, the region has been a victim of the adverse effects of climate change in the form of an increased frequency of floods and droughts, which have led to reduced crop yields, and have made it increasingly vulnerable to food insecurity and all its attendant consequences (Brown, Hintermann et al. 2009). Furthermore, West Africa has long been reputed to have abundant energy resources to fuel its needs, which include renewable sources like hydroelectric energy, solar energy, wind energy, tidal energy, biomass energy, geothermal energy and fossil fuels such as oil, natural gas, coal and charcoal (Iwayemi 1983). However, very few of those resources are available to the majority of the population who still rely on traditional biomass to satisfy basic needs such as cooking and heating.

Despite the significant effort that will be required to electrify the entire population (about 80% of the population is without access to electricity), the region has a unique opportunity to develop a novel type of electricity sector through "leapfrogging", and by benefitting from the experiences of the more technologically advanced parts of the world. In other words, the question is, should the region follow the well charted path followed by industrialized nations, but which has proven retrospectively to be unsustainable and which they are trying to move away from? Or should it embark on a more sustainable but challenging path that is essentially unmapped? This dissertation will try to grapple with this question using a variety of techniques and policy approaches, and can be considered to be an exercise in what has been termed "reflexive modernization" (Grin, Felix et al. 2004).

The next section of this chapter gives a background of West Africa and the institutions that are responsible for economic integration and regional energy planning followed by an overview of the centralized and distributed approaches to the generation of electricity. It then provides a description of the methodology that I follow in the dissertation project, after which I explain the way that I operationalize the adaptive management framework. The next section provides a brief overview of the environmental values that can guide electricity planning in the region and lastly, I present an outline of the dissertation.

## 1.2 Background to the Electricity Sector in West Africa

The West African subregion is comprised of 15 independent states which established a community in Lagos, Nigeria in May 1975 known as ECOWAS (Economic

Community of West African States), cutting across linguistic, historical and cultural differences for the purpose of economic integration (Asante 1997).

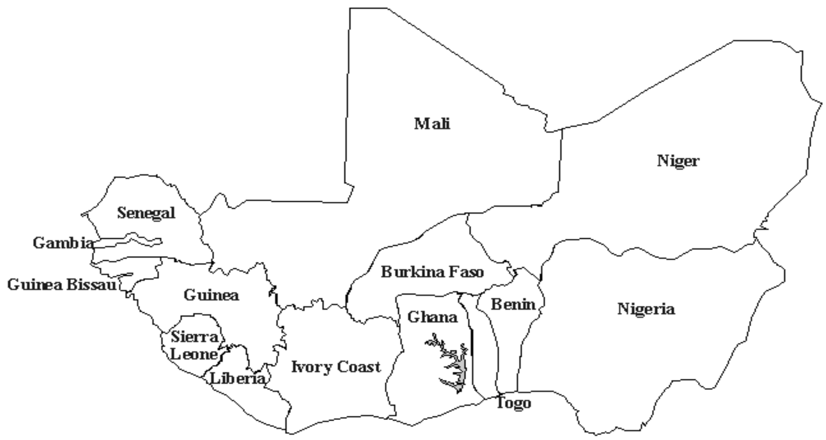


Figure1.1 Map of ECOWAS Member States (Purdue 2009)[1]

Only about 20% of West African households have access to electricity and the per capita electricity consumption is 88 kWh per year as compared to 11,232 kWh in the U.S. with 100% electrification, that is, more than 120 times as high (UNDP 2009). The urban population is about 43%, about half of which consists of the urban poor (UNDP 2009). With the exception of Ghana and Cape Verde, all ECOWAS countries have a Human Development Index of below 0.5 and are ranked among the 30 lowest in human development index (HDI) (UNDP 2009). Table 1 below shows the descriptive statistics of the ECOWAS region contrasted with those of the United States (U.S.), which has a similar size and population but is an industrialized nation.

[1] The islands that make up Cape Verde are located to the West of Guinea Bissau but are not shown on the map

Table1.1 Descriptive socio-economic statistics of ECOWAS (UNDP 2009)

| ECOWAS | U.S. |
|---|---|
| 15 member nation states | 50 states + District of Columbia |
| Population: 262 million | 307 million |
| 6 million sq. kilometers | 9 million sq. kilometers |
| GDP per capita: $1400 | GDP per capita: $45,000 |
| Urban Population: 43% | Urban Population: 81.4% |
| House hold Access to Electricity: 19% | Household Access to Electricity: 100% |
| Electricity consumption per capita: 88kWh per year | Electricity consumption per capita: 11232 kWh per year |
| Ranked among 30 lowest in Human Development Index | Ranked #13 |
| One non-contiguous state (Cape Verde Islands) | Two non-contiguous states (Alaska and Hawaii islands) |

Furthermore, the total demand forecasted for 2010 is shown in Table 2 and Figure 2 below indicating the proportion of the demand that was met and that which was not. It should be noted that despite the growing power demand, an average drop in generation of 1.41 % was recorded instead of the expected 6 - 7% growth from 2006- 2009.

Table 1.2 ECOWAS Electricity Demand in 2010 (WAPP 2010)

| Proportion Supplied | Electricity Demand (GWh) | Percentage (%) |
|---|---|---|
| Met Demand | 51,925 | 53% |
| Unmet Demand | 46,516 | 47% |
| **Total Forecast** | **98,441** | **100%** |

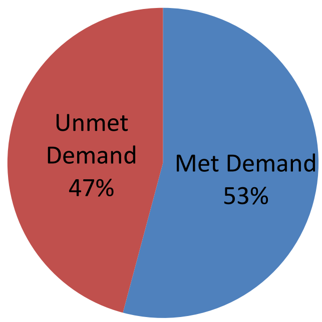


Figure 1.2 Proportion of ECOWAS Electricity Demand in 2010 (WAPP 2010)

ECOWAS has established three flagship energy programs in order to meet the expected increase in demand in the region, namely:

1.) The West African Power Pool (WAPP): Its role is to integrate the national power utilities into a unified regional electricity market, to quadruple inter-connection capacities within the next 20 years, and to generate additional electricity capacity.

2.) The West African Gas Pipeline (WAGP): Its purpose is to construct a 600 km pipeline to transport natural gas from Nigeria to Benin, Togo and Ghana for electricity generation and industrial purposes (ECOWAS 2006).

3.) The Regional Centre for Renewable Energy and Energy Efficiency (ECREEE): This center was created in Cape Verde in July 2010 to address renewable energy development and the role of decentralization in rural electrification (UN 2010).

## 1.3 Approaches to Electricity Generation

### *1.3.1 Centralized Generation: The "Master Plan" of the WAPP*

The current Master Plan of the West African Power Pool (WAPP) identifies oil, gas and hydropower as the primary energy resources in the region and selects natural gas as its choice for new power generation (Nexant 2004). In addition to new power generation from natural gas, the focus of WAPP is on building a robust grid that facilitates long distance transmission as a viable solution for energy-scarce landlocked countries and the regional integration of national markets that can provide economies of scale for countries such as Benin and Togo that are too small to justify large scale generation plants of their own (ECOWAS 2006).

The electricity generation capacity of the various sources of energy in West Africa is shown in Table 1.3 and their relative proportion in the fuel mix is shown Figure 1.3 below.

Table 1.3 Sources of Energy for Electricity Generation in ECOWAS in 2010 (WAPP 2010)

| Source of Energy | Capacity (GWh) | Percentage (%) |
|---|---|---|
| Thermal | 37,328 | 64 |
| Hydro | 18,458 | 31 |
| Import + Others | 2,877 | 5 |
| **Total** | **58,663** | **100** |

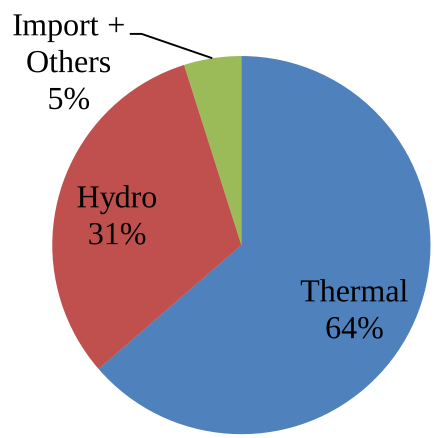


Figure 1.3 Proportion of Energy Resources in ECOWAS in 2010 (WAPP 2010)

The WAPP model divides the states into two zones, Zone A (Nigeria, Niger, Benin, Togo, Ghana, Côte d'Ivoire and Burkina Faso) and Zone B (Mali, Mauritania, Senegal, Gambia, Guinea, Sierra Leone, Liberia and Guinea Bissau) in order to implement its proposed developments through 2020. In Zone A, the countries that generate electricity are Ghana and Côte d'Ivoire. Ghana has committed to supplying Benin and Togo with electricity even though it is unable to fulfill all its own electricity requirements. It has two major hydroelectric power plants, the large Akossombo Dam and the smaller Kpong Dam and one thermal (natural gas plant) (Opam and Turkson 2000). A third dam, the Bui Dam is currently under construction in Ghana as well.

Côte d'Ivoire has a large thermal plant at Vridi and five hydroelectric dams and sells power to Ghana, to Burkina Faso and more recently to Benin and Togo as well (N'Guessan 2000). Nigeria's dams at Kainji, Jebba and Shiroro provides all its major cities with electricity (about 40% of the population), albeit inadequately, and has also supplied the Republic of Niger since the 1970s (Gnansounou, Bayem et al. 2007). The two main dams that supply Zone B, in particular Senegal, Mali and Mauritiania, are the Manantali and Diama dams (Bader, Lamagat et al. 2003). In 2009, construction began for the Felou hydroelectric project in Mali (Xinhua 2009). Figure 4 below shows a map of the WAPP interconnections with already existing connections, those that are proposed for the regional power pool, and one that was proposed by the continental agency known as New Economic Plan for Africa's Development (NEPAD).

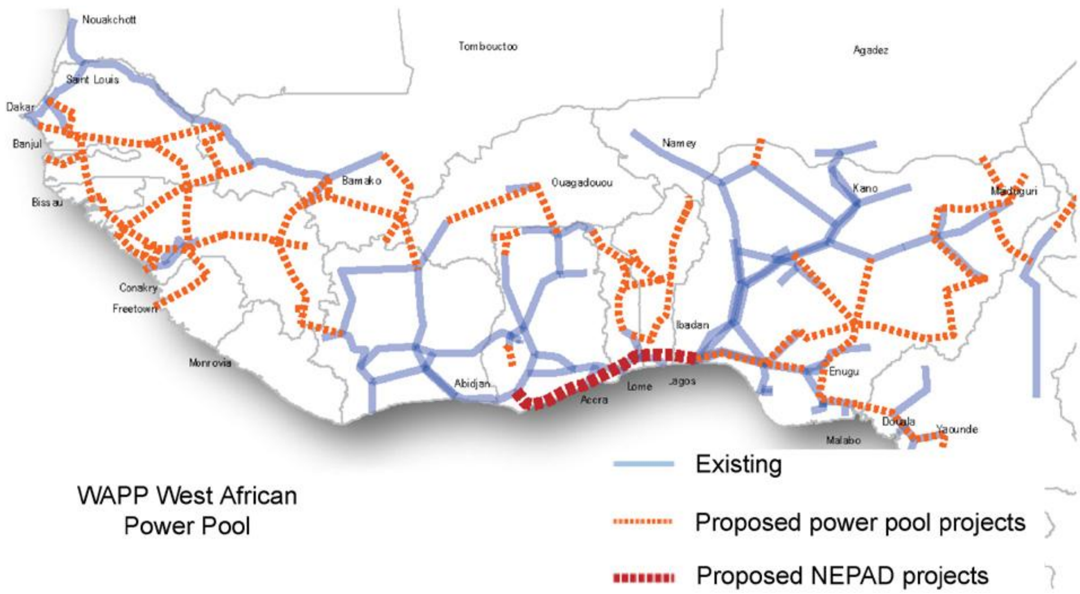


Figure 1.4 West African Power Pool (WAPP) Interconnections (Pineau 2008).

The bulk of the published literature on electricity planning in West Africa focuses on the advantages of integrating and restructuring the power sector in West Africa (Mebratu and Wamukonya 2007; Dayo 2008; Pineau 2008). The emphasis on reform and restructuring is part of the wave of liberalization that has swept the world since the 1980s and it is characterized by three trends: the first is the desirability of market solutions, the second is the emergence of a political climate that would advocate for privatization as a means of change and the third is the poor technical, economic and financial performance of electric utilities as well as the shortage of capital for infrastructure (Turkson 2000).

The main focus of the reform in Ghana has been on allowing the principles of a competitive market to operate the generation aspect of the industry, while distribution and transmission are regulated by an independent regulatory body which would institute regulatory incentives for the operators in these segments in order to meet the government's goal of making electricity accessible to all of Ghana's residents by 2020 (Opam and Turkson 2000). In Côte d'Ivoire, privatization was carried out very quickly but it neither showed the sharp increase in the payment of bills by consumers that was anticipated, nor did the quality of service clearly improve (N'Guessan 2000). However, N'Guessan (2000) reported that with the exception of periods of social and political turmoil, the financial stability of the power sector in that country had been restored by the year 2000, implying that at least one of its goals was achieved.

### *1.3.2 Distributed Generation*

The creation of the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) is intended to implement the vision and recommendations for increased access outlined in the White Paper for a Regional Policy on Access to Energy Services published by ECOWAS in 2006. In this paper, there is a formal recognition of the importance of the future role of renewable energy in development as well as the use of decentralized grids for rural electrification but there is no explicit strategy in that regard. This approach is covered under the term Distributed generation (DG), which refers to a set of small-scale technologies and approaches to energy management that generate power in close proximity to its point of consumption (Sovacool 2006).

Renewable energy technologies generate electricity from the sun, wind, waste or biomass; and together, they can help reduce greenhouse gases and other harmful byproducts of traditional sources of power such as oil, natural gas, coal or nuclear energy. They also offer many other advantages in large part due to their flexible nature. A wide range of synonymous terms have been used to describe the concept of DG in the literature such as “distributed power”, “distributed resources”, “embedded resources”, “micro-power”, “modular power”, “on-site generation” and “self-generation”. It is also used reciprocally with “combined heat and power” (CHP), “cogeneration” or “trigeneration” because they generate electricity near the site of its use (Sovacool 2006). Table 1.4 below shows the efficiency characteristics of DG and conventional technologies as well as their respective technical challenges and advantages.

Table 1.4 Characteristics of some Distributed Generation and Conventional Technologies (Sovacool 2008).

| Technology | Characteristics | | | |
|---|---|---|---|---|
| | **Thermal Efficiency** | **Capacity** | **Challenges** | **Advantages** |
| Wind Turbine | N/A | 1 kW – 5MW | Intermittency | Free fuel, declining production costs |
| Solar PV (Individual Cell) | 7 – 17 % | 1 W – 10 kW | Intermittency, low capacity, high cost | Free fuel, compactness |
| Biomass Generator | 40% | 20 - 50 MW | Air pollution, low fuel energy density | Widely available fuel |
| Small Hydro | N/A | 200 W - 10MW | Low storage capacity, seasonal | Free fuel |
| Large Hydro | N/A | 10 – 14,000 MW | High capital cost, biodiversity loss, displacement of people | Inexpensive fuel (but can be competitive) |
| Natural Gas | 25 – 30% | 200 – 1000 MW | Transmission losses, GHG emissions, price volatility | Burns more efficiently than coal or biomass |

The relatively high initial cost of purchasing DG technologies (particularly solar and wind) is often cited as a barrier that prevents utilities, communities and citizens from investing in them. However, an analysis of the Levelized Cost of Electricity (LCOE) allows alternative energy technologies to be compared, which may have different operating lifetimes, different scales of operation, and different investment time periods, is more illuminating than simply looking at the initial or capital cost (Short, Packey et al. 1995). The LCOE for a given technology is its cost per kWh, and is calculated by dividing the present value of all the system costs (including fuel costs, fixed and variable operating costs) by the present value of all the electricity generated during its lifetime. In its simple form, it can be written as:

LCOE = PV [Costs] / PV [Electricity Generation].

A comparative study of the LCOE of energy technologies used in three rural regions of Senegal that also took into consideration negative environmental externalities from fossil fuel use, revealed that decentralized solar PV and wind technologies are cheaper than both diesel generators ( as shown in Table 4), as well as electricity from grid extension (Thiam 2010).

Table 1.5 Levelized Cost of Electricity (LCOE) for DG Technologies Used in the Rural Regions of Kaolack, Thies and Fatick in Senegal (Thiam 2010)[2]

| Technology | LCOE in 2010 ($/kWh) |
|---|---|
| Diesel generator | $1.18 |
| Wind Turbine | $0.24 |
| Solar, PV | $0.19 |

In Nigeria, the National Electric Power Authority (NEPA) was deregulated into local distribution network operators (DNOs), but it remains to be seen whether these DNOs have a reliable network and whether they will abuse their monopoly power to prevent DG operators from getting suitable remuneration from their contribution to the grid (Odubiyi and Davidson 2003; Dayo 2008). Furthermore, it is thought that the open investment climate brought about by the deregulation of monopoly utilities will

[2] Thiam (2010) provides the final LCOE values in F CFA. The values in the table reflect the conversion rate of $1 US = 489.207 FCFA listed in the paper.

ultimately serve to encourage the adoption of autonomous or non-autonomous microgrids with various DG resources (Blyden and Lee 2006).

### 1.4 Policy Analysis: Reframing the ECOWAS Strategy

The WAPP policy documents, in particular the master plan, are based primarily on technical and economic considerations. The few references to environment and social impact assessments done in other studies are made only in terms of how much they would cost to implement with respect to the total estimate. For example, the original master plan stated that the cost of implementing the environmental and social impact plan would be less than 1% of the total cost in the case of a particular transmission interconnection between Côte d'Ivoire and Burkina Faso (Nexant 2004). Furthermore, the revised master plan states that it has evaluated the possible social and environmental impacts of the regional priority projects and has integrated the additional costs attributable to environmental constraints into its final results (Tractebel 2011).

Thus, the documents provide seemingly value-neutral assessments, upon which it bases the rigor of the study. This type of linear, rationalist, and technocratic policy analysis has been challenged in the last two decades due to its positivistic underpinning and its overwhelming dependence on the assumptions of neo-classical economic theory (Fischer 1998). Some of the challenges are that this kind of analysis tries to sidestep the partisan and value conflicts typically associated with policy issues, whereas its role should more be to stimulate and improve the quality of argumentation in policy deliberation, than to provide answers to societal problems (Fischer 1998).

Nevertheless, the first part of this project employs a traditional policy analysis to reframe the existing ECOWAS energy policy documents and presents the current energy situation in West Africa in a more explicit format that uses the same set of criteria to analyze both centralized generation and distributed generation. This type of analysis can be referred to as a technical-analytic discourse, which seeks to verify whether the program has fulfilled its stated objectives, fulfills some more efficiently than alternative ones, or whether there are secondary or unanticipated effects that offset the program (Fischer 2007).

### *1.4.1 Stakeholder Analysis*

Stakeholder analysis (SA) is an important tool for policy analysis and is an approach to understanding a system and the changes it undergoes by identifying the key stakeholders and assessing their interests within the system (Grimble and Wellard 1997). It has a significant potential in natural resource policy and can help to clarify the stakeholders in West Africa's electricity policy and their affiliated institutions in order to understand the systems and developing knowledge that would be useful for the incorporation of AM into the analysis. This categorization of the stakeholders and their interests will be done based on the information gathered from the policy documents and from interview data that will be gathered as indicated subsequently in the plan of analysis.

### *1.4.2 Life Cycle Assessment of Technology Options: A Review*

A life cycle assessment of various energy technology options will be provided through a brief review of the literature on the subject. The purpose is to present data about resource consumption relative to emissions produced, which have been used to quantify the environmental impact of different technologies, particularly those that are being used in West Africa.

### *1.4.3 Outcomes:*

The basic goals or outcomes of a given electricity sector with a view toward the public interest can be classified as social (support for basic services such as health, education and clean water), industrial (improved mechanization, agricultural productivity, communication and resource transformation capability), environmental (reduced pollution) and national (national autonomy) (Pineau 2002). These goals apply equally to the West African electricity sector and can be restated in the form of the questions below.

1. Social goals: Do they improve electricity access rates and affordability of access?
2. Industrial goals: Do they improve the agricultural productivity and extended resource transformation potential?
3. Environmental goals: Do they reduce the ecological footprint?
4. Regional goals: Do they improve local, national and regional ownership of the electricity sector, and increased scientific, technological and innovation capability in the sector?

### *1.4.4 Evaluative Criteria:*

The criteria that I use to evaluate whether the objectives or expected outcomes of the West African electricity sector as outlined above are organized based on Bardach's typology into the four broad categories of technical feasibility, economic and financial possibility, political viability, and administrative operability (Patton and Sawicki 1993). I add a fifth criterion to these four, which is environmental sustainability, because it is a critical one, particularly for the power sector. More specific criteria that are evaluated under each are listed below.

1. Technical Feasibility:
   - *i. Effectiveness:* Have the results articulated in the vision of the official agencies been achieved so far? For instance, are the existing energy resources and electricity infrastructure able to satisfy the current demand in the region? In the case of centralized generation, this will be based on the amount of natural gas reserves and hydroelectric potential in the region as reported by the WAPP, while for DG it will be determined from modeling the average climatic characteristics of the region such as average solar radiation or average wind speed
   - *ii. Adequacy:* To what extent have the core problems been addressed by these policies?
2. Economic and Financial Possibility:
   - *i. Cost effectiveness:* Have the objectives of the policies been achieved at minimum cost? For instance, how can the costs of electricity generation for DG and CG can be compared adequately to determine which options can be provided at the lowest cost? How are these costs distributed among wholesale and retail customers?

These will be determined using the Levelized Costs of Electricity (LCOE) and software optimization tools.

ii. *Efficiency:* Have the human, financial and technical resources been used in the most cost-effective and efficient way?

3. Political Viability:

i. *Appropriateness:* Have the policies and strategies been appropriate for meeting the requirements of the overall policy context? For example, are the efforts being made toward power sector reforms such as vertical unbundling of generation, transmission and distribution, or horizontal unbundling (that is separation into smaller utilities) appropriate to the overall policy context? Are the few existing DG programs that are being run suitable to the context?

ii. *Responsiveness:* Have the policies been responsive to the needs and requirements of the stakeholders?

iii. *Equity:* To what extent have the policies helped to reduce vertical inequalities (income-based), increase representation by various demographics, and ensure equity in employment?

4. Administrative Operability:

i. *Authority:* Does the implementing organization have the authority to convert policies into programs or make incremental changes?

ii. *Capability and Organizational Support:* Does the financial and technical staff of the implementing organization have the necessary skills to implement the policies as well as the infrastructure to do so?

iii. *Institutional commitment:* Are top administrators and other office and field staff committed to policy implementation?

5. Environmental Sustainability:
   i. *Environmentally-sensitive technologies:* Do the energy technologies used have a low environmental impact?
   ii. *Environmental policy considerations:* Are the environmental consequences of energy use taken into account in the policies?

## 1.5 Adaptive Management and Energy Policy

The literature suggests that electricity reforms in Africa in general, have not put forward a comprehensive environmental strategy, and as such, the linkages between the electricity sector and the environment are weak (Pineau 2006). Even though strong environmental impact studies have been done for new power plants, all types of investments are being made ranging from fossil fuel expansions of diesel, heavy fuel oil, and natural gas, to large hydroelectric projects, while most citizens continue to use fuel wood (Pineau 2006). This lack of policy coherence calls for an integrated energy-environment process that can increase the likelihood of long-term sustainability (Pineau 2006).

The framework that will therefore be used to carry out this aspect of the analysis in this project is that of Adaptive Management (AM), which can be defined as an approach to understanding, justifying and implementing policies that affect the environment (Norton 2005). It is an integrated analysis that views sustainability as the outcome of appropriate deliberation which does not yield a single decision point but rather iterative and reversible decision making to mitigate unforeseen consequences.

As opposed to a traditional "science of parts", where the aim is to reduce uncertainty until there is near unanimous agreement among scientific peers, AM is a science of the integration of parts, which uses the results of the first, but recognizes that knowledge of a given system is necessarily incomplete. It therefore seeks actions that satisfy social objectives, achieve continued understanding of constantly evolving conditions, and provide the flexibility to adapt to surprises (Holling 1995). Thus, AM views policies as experiments that probe the behavior of natural systems, and since resource management is recognized as being inherently uncertain, any surprises are seen as opportunities to learn as opposed to failures to predict (Lee 1991). Furthermore, by merging the systematic gathering of scientific information with a forum of affected parties, the AM process can help with making difficult management decisions (Wieringa and Morton 1996).

Following in the tradition of pragmatist philosophy, proponents of AM argue that a theory of environmental management must be a theory of action. It can be said to be based on three central tenets or defining characteristics, namely, experimentalism, multiscalar analysis and place sensitivity (Norton 2005). Experimentalism requires adaptive managers to take actions based on experience that are able to reduce uncertainty in the future. Multiscalar analysis then requires them to understand the environment as a complex interaction of parts and requires them to keep track of their actions as they emerge over space and time. Finally, place sensitivity requires a commitment to consider not only the geographical location, but also place-based values while examining a given problem (Norton 2005).

The three main theoretical foundations of sustainable development are social theory, ecology and evolution, and economics, while the corresponding practical foundations are community empowerment, conservation and environment, and business development, respectively (Yorque, Walker et al. 2002). The correspondence between theory and practice is shown in Figure 1.5 below, where the vertices in the triangle of practice rest on the theoretical foundations of those in the triangle of theory, but an integrative theory is sought which can better guide practice.

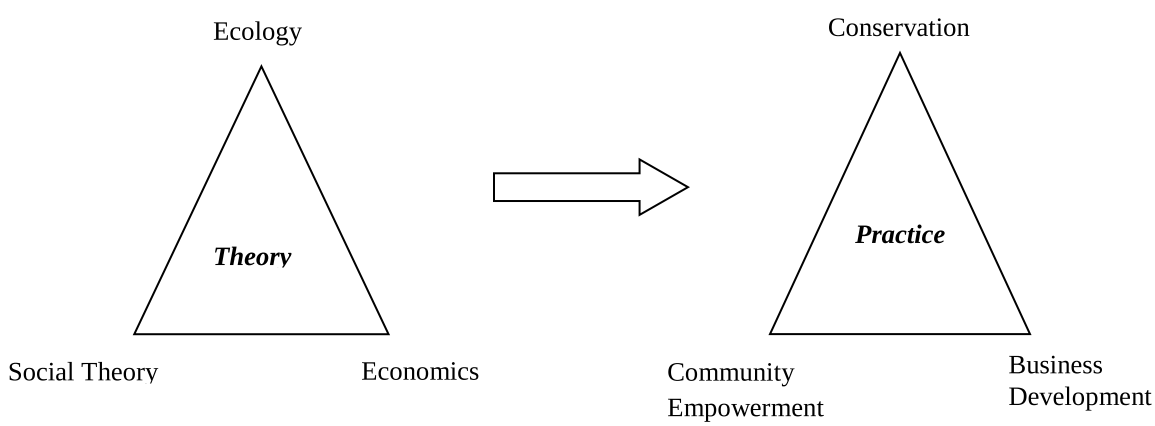


Figure 1.5 Theoretical and Corresponding Practical Foundations of Sustainable Development (Yorque, Walker et al. 2002).

One of the founding theorists of Adaptive Management, C.S. Holling, has argued that the ecological, economic, and social components of the quest for sustainable development have an evolutionary character because problems cannot be solved based only on knowledge of a small part of a whole, or on assumptions of stable or constant relationships as these would lead to rigid institutions and more vulnerable natural systems (Holling 1995). As a consequence, evolutionary theory is best suited for the natural science or ecological component, actively adaptive policy designs that yield understanding as well as product are suited for social component, while learning and innovation are best suited for economics and organizational theory (Holling 1995).

### *1.5.1 Review of Previous Studies*

Adaptive management has been applied to the context of ecosystems where centralized power systems play a major role. The best known example is with respect to hydroelectric power, energy efficiency, and environmental rehabilitation at the Northwest Power and Conservation Council (NPCC) in the 1980s (Lee 1991), for modifying water releases to improve aquatic habitats at the Tims Ford Dam managed by the Tennessee Valley Authority (TVA 2008), and for managing biodiversity and downstream resources that are affected by hydropower operations at the Glen Canyon dam (Wieringa and Morton 1996).

### *1.5.2 Criteria for assessing the viability of an Adaptive Management program*

Gregory, Ohlson et al. (2006) have proposed a set of criteria for assessing the appropriateness and relevance of an AM program by the four topic areas listed below. I then evaluate the three case studies of AM concepts applied in both the U.S. and West African contexts with respect to these criteria.

1. Spatial and Temporal Scale: Are the duration, spatial extent and complexity, and external effects sufficiently addressed in the program?
2. Dimensions of Uncertainty: Has the AM program narrowed down the type of uncertainty that is most likely to influence management decisions? For example, parameter uncertainty, structural uncertainty, stochastic uncertainty (random, natural), confidence in assessments.
3. Costs, Benefits, and Risks: Have the costs and benefits, magnitude of effects (predictability), multiple objectives, and risk of failure been adequately specified?
4. Stakeholder and Institutional support: Are leadership, decision-making flexibility, institutional capacity, and ability to avoid trade-offs that may be considered taboo by some stakeholders, adequate to monitor AM plans?

Following this AM analysis, I discuss three additional considerations that address the requirement of place-based sensitivity in implementing an AM program in the West African context. These include alternative ownership patterns and financing mechanisms, suitability as "intermediate" technologies, and environmental values.

### *1.5.3 Learning and Innovation in Clean Energy in West Africa: Lessons from Denmark, China, and South Africa*

The concept of “learning” is central to the AM framework, where it refers to social learning and learning by doing on the basis of which better policies and better experiments can be designed (Lee 1993). This concept takes on an evolutionary perspective and is central to the three main branches of AM which need to be integrated to achieve sustainable outcomes, namely, the social, ecological and economic factors. While the social (i.e. organizational and policy aspects) and ecological aspects are adequately covered in the description of the framework above, the evolutionary aspect of the economic pillar is not sufficiently dealt with. Indeed, it is best dealt with through the analysis of learning and innovation in both practices and technologies.

In the Systems of Innovation (SI) framework, learning refers to the process of technical change achieved by diffusion, or the absorption of innovations produced elsewhere, and incremental innovation of the acquired techniques (Viotti 2001). The concept of learning in both frameworks is compatible and analogous (innovations as experiments and policies as techniques), and for the purpose of assessing the potential for local innovation in clean energy, whether centralized, incorporated in a centralized system as a DG, or a stand-alone DG. I employ the SI framework for this part of the analysis since technological innovation, as one of the industrial and regional goals, has been explicitly identified as one of the desired outcomes of the electricity sector in West Africa.

This section discusses the need for "clean" or environmentally sustainable technologies to be an important part of the equation when discussing approaches to

Science, Technology and Innovation (STI) policy in light of the causes and consequences of climate change. The comparative analysis consists of the following steps.

1. Characterization of the System of Innovation with respect to Clean Energy Innovation of West Africa, Denmark and China:

Here, I characterize West Africa's innovation policy with respect to clean energy (as described for instance in the ECOWAS White Paper on Energy Access) and likewise characterize those of Denmark (mainly wind) China (solar, wind and biomass), and South Africa (solar and wind). I selected Denmark because until recently, it was ranked first in the number of wind turbines produced, it has a well-developed clean energy innovation program, and is comparable in size to a number of small West African Countries.

Secondly, I selected China, because it is ranked first in solar PV production, wind turbine production, and in the production of biogas digesters. Furthermore, it is a Newly Industrializing Country, and its landmass and population are larger than the West Africa Region as a whole. Thirdly, I have also selected South Africa because it is the only semi-industrialized country in sub-Saharan Africa, and as such, it exhibits both features of an industrialized country and those of a non-industrialized one. It has by far the highest electrification rate in sub-Saharan Africa, a feat that was achieved in a period of about 10 years, and seeks to further expand electrification while increasing local content in the technologies used.

2. Lessons learned:

I apply some of the general lessons from China, Denmark, and South Africa to the West African region. I then underscore specific lessons to be learned with respect to innovation for electrification generally, and for clean energy innovation in particular.

## 1.6 Research Questions

The possible combinations of technological (electricity generation) and management approaches to electric power planning in West Africa are shown in the matrix in Table 6. Each quadrant in the table is associated with a research question (Q1 – Q4) described below.

Table 1.6 Technological and Management Options for Electric Power Planning

| | Centralized Management(CM) | Adaptive Management (AM) |
|---|---|---|
| Centralized Generation (CG) | WAPP, Volta River Authority [Q1] | NW Power Council, Glen Canyon Dam [Q3] |
| Distributed Generation (DG) | China, Denmark [Q2,Q4] | Songhaï Centre, Benin [Q2,Q4] |

Given the overview of the electricity sector in West Africa provided, the questions that this research attempts to answer are the following:

Q1. How can the current centralized approach to electricity generation meet the energy demand in West Africa?

Note: The answer to this question is contained in the data provided by the WAPP in its official documents and is included here for the purpose of presenting a symmetric analysis with DG.

Q2. Could Distributed Generation satisfy the energy demand shortfall? If so, how?

Q3. Is the concept of Adaptive Management being used to manage issues associated with electric power production in West Africa? If so, to what extent?

Q4. How might the social, economic and political conditions in the region support or challenge Adaptive Management? What role might innovation in energy technologies play in the AM process?

## 1.7 Plan of the Analaysis

The overall strategy to address the problem statement consists of applying two main theoretical approaches. In the first instance, I reframe the ECOWAS policies into a coherent policy analysis, which includes a traditional policy analysis based on specific criteria, and applied symmetrically to the two approaches to electricity generation. In the case of centralized generation where explicit policies exist, the WAPP documents are the primary sources of textual data, but I also use some national level policies where relevant. These documents also contain the quantitative analyses of the technical potential and economic costs of the plan.

In the case of distributed generation, which is referred to, but with no explicit strategy, I use the 2006 White Paper for a Regional Policy to carry out a prospective policy analysis using the same criteria that were used for the centralized plan. The sources of data used here are the existing formulations in the ECOWAS policy documents, and other national policies. The quantitative estimates of energy production and cost are obtained from a review of published studies that offer a range of such figures in conjunction with a decision analysis software tool for modeling worldwide clean energy production. For both centralized and distributed generation, the aspects of the analysis that lend themselves to a process of deliberation use interview data with stakeholders in order to obtain information and insights that are not explicitly stated, or cannot be determined from the written documents.

The main theoretical framework is adaptive management (AM), which consists of “mission-oriented” or post-disciplinary science (as opposed to disciplinary or curiosity-driven science), as well as the evaluation of existing options. Both of these are embedded within a larger procedure wherein the purpose is to attain an ongoing discourse about policies that is fair, open, iterative and reversible. The hypotheses I advance for the adaptive policy analysis of the West African electricity sector are mainly informed by a study of AM programs in the Columbia River Basin, which was the first time the framework was used to develop a plan for a regional power system in the U.S. Two other examples where AM has been applied, namely, at the Glen Canyon Dam, and in the Tennessee River Valley, are additional case studies for the purpose of comparison that can either reinforce those of the Columbia River Basin or offer other hypotheses.

I then assess the environmental impacts of hydropower generation in the Volta River Basin (VRB) in Ghana and the impact of dams in the Komadugu-Yobe Basin (KYB) in Nigeria, which is not yet being used for power generation. Those assessments are carried out in order to determine to what extent they satisfy the requirements of AM and determine what is needed to fulfill those requirements. The analysis of deliberation is informed by discussions from the interview process, and is closer to the ordinary language type of policy argumentation used by politicians, policy makers and the larger public (Fischer 2007).

The first two case studies above, namely, the VRB in Ghana and the KYB in Nigeria, will be assessed based on the AM criteria derived from the experiences in the Columbia River Basin, the Tennessee River Valley, and at the Glen Canyon Dam. Furthermore, there are preliminary indications that some elements of AM are already being incorporated into dam management in Ghana based on newsletters of the Ghana Dams Forum and minutes of national meetings of the national dialogue on dams published online (GDF 2009). However, following the release of the report, “Dams and Development: A New Framework for Decision-Making” by the World Commission on Dams (WCD), which offers a roadmap for the best international practices against which new projects can be measured, most African countries were yet to implement its recommendations (ARN 2006). The report describes the process that brought conflicting interests such as the dam industry, governments, and civil society organizations to the table, as well as the assessment of available options in a transparent and participatory manner.

The three West African case studies therefore include the Ghanaian case (VRB), where some explicit elements of AM have been applied, the Nigerian one (KYB), where no explicit AM has been applied, and the Beninese case (Songhai), where all the elements of AM appear to have been applied, although using different terminologies. The lessons learned from answering Question 3 combined with the Danish, Chinese and South African experiences with clean energy innovation (an exploration of the evolutionary economics component of AM) are used to answer Question 4.

Informed by the case studies described above, I put forward the following hypotheses in order to help clarify the potential impact or lack thereof of an AM process on electric power management in West Africa.

H1. The use of Adaptive Management principles to monitor the environmental impacts of dams in the Volta River Basin (VRB) in Ghana has led to more reliable power supply, and better social and environmental conditions than in the Komadugu-Yobe Basin (KYB) in Nigeria where AM was not used.

H2. The low degree of interaction between political and economic stakeholders on one hand, and social actors on the other, undermines social and policy learning with respect to regional plans for electrification.

H3. The low level of domestic ownership of the electricity sector in West Africa negatively impacts the widespread implementation of regional plans.

H4. The general condition of weak local technological capability promotes turnkey solutions to technological challenges. The adoption of such solutions undercuts the ability of the region to build an innovation system around renewable energy.

A flow chart of the plan of analysis is shown in the figure below:

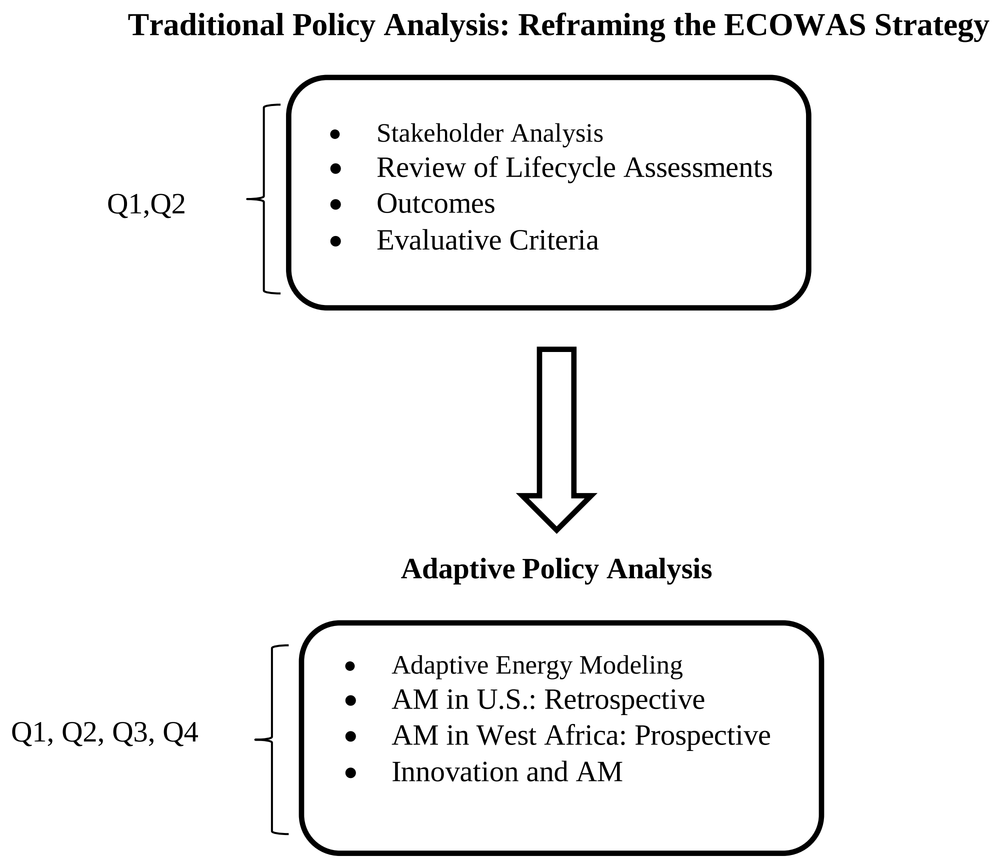


Figure 1.6 Dissertation Analysis Plan.

## 1.8 Data Sources

The various types of data sources that were used in this dissertation are listed below. In addition, the list of the stakeholders who were interviewed is presented in Appendix A.

1. Regional Electricity Planning Documents: These include both the original and revised master plans of the WAPP, the White Paper for regional energy access, and the ECOWAS Energy Protocol. The list of
2. Literature Review: Publications and books on electricity planning, deliberative policy analysis, adaptive management, innovation studies, comparative international experiences, etc.
3. Environmental and Social Impact Assessments: These include the formal policy documents that assess the environmental concerns of the WAPP for generation and transmission infrastructure, and for individual hydroelectric power planning authorities in West Africa.
4. Strategic Plans: These include the Glen Canyon Dam Adaptive Management Program's (GCDAMP) 1996 Record of Decision, The TVA's Reservoir Operations Study and Tims Ford Dam AM Program, and the Power Plans and Fish and Wildlife Plans of the Northwest Power and Conservation Council.
5. Electricity Modeling and Analysis: I estimate the electricity generation potential from distributed and renewable electricity using satellite data from NASA for the average solar insolation and wind speed based on the geographical coordinates of two diagonally positioned cities in a given country. I have also used the HOMER (Hybrid Renewable and Distributed Power Design Support) energy modeling software package to optimize the costs associated with these diesel, solar, wind and biomass energy. The capital and operating costs associated with these systems are obtained from secondary survey data from West Africa published in the peer reviewed literature. HOMER can design and analyze a mix of conventional and distributed

generators and can determine the financial feasibility of a hybrid energy system. It is a free software package that allows the user to do sensitivity analyses. It also has great graphical output.

6. Technology Assessment: I provide a comparative literature review of selected centralized and distributed generation technologies on the basis of life cycle assessments.
7. Interviews with Stakeholders: These stakeholders are officials and representatives of national and regional electricity planning organizations and non-governmental organizations in West Africa. They also include representatives of U.S.-based agencies that have implemented adaptive management in contexts where energy planning is involved, namely, at the Tennessee Valley Authority (TVA), at the Glen Canyon Dam, and at the Northwest Power and Conservation Council (NPCC).

## 1.9 Outline of Work

Chapter Two reviews the relevant literature that on adaptive management, energy policy, and innovation systems that serves a foundation for this dissertation. It recognizes the precursors of the idea of AM, and highlights the work of some of its founding theorists. The chapter surveys its applications to ecosystem contexts where energy production is one of the human activities, in order to illustrate how the concept deals with the challenge of having multiple, and often conflicting interests.

Chapter Three presents a policy analysis of the ECOWAS strategies in order to provide a more coherent depiction of its electricity sector. It gives a description of the stakeholders in the sector, their interests, and their relationships to each other, it offers a review of life cycle assessments of energy technologies, with an emphasis on those being used in the region, and it explicitly describes the expected outcomes of the electricity sector in West Africa. All the different analyses are employed to inform the assessment of the region's electricity policies based on traditional criteria that are used for policy evaluation.

Chapter Four, Five and Six directly grapple with the question of applying adaptive management to energy policy. Chapter Four presents a quantitative analysis of the potential of biomass energy, solar energy and wind energy to meet the power supply demands of the region in comparison with the conventional energy resources. It then does a modeling-based analysis of five possible scenarios for off-grid distributed generation of electricity and evaluates their relative costs and environmental impacts.

Chapter Five explores the past and ongoing efforts to apply adaptive management to three ecological systems in the U.S. where the power generation potential is seen as a central resource for the regions that they are located in. It applies a number of criteria for assessing whether an AM program is appropriate to the three U.S. sites from a retrospective viewpoint. Chapter Six then investigates three West African sites, two of which are analogous to the U.S. sites in the sense that they are river basins, in order to assess the potential for AM to address the particular problems in their respective region. The analysis in this chapter is done in a prospective or *ex ante* perspective because AM is not a formal policy in any of them. It also extends the analysis of the U.S. cases by including three additional criteria that can be considered to be more precarious in a West African context.

Chapter Seven then pursues one of the perceived weaknesses of AM, which is its relative inattention to questions of technological innovation. It employs the systems of innovation framework, which has a number of parallels with AM, particularly in terms of the centrality of the concept of learning in both approaches. Because there is a weak system of innovation in West Africa, particularly with respect to modern clean energy systems, the chapter carries out the analysis in comparative perspective with three other countries whose trajectories have been tracked and could offer some lessons to the region. These countries include China, Denmark and South Africa.

Finally, Chapter Eight summarizes the key findings from each chapter and connects them together to offer some general conclusions. It also offers some policy implications of these findings for sustainable electricity planning in West Africa.

# Chapter Two

# LITERATURE REVIEW

## 2.1 Overview of Adaptive Management

This literature review seeks to provide an overview of some of the antecedents of the concept of adaptive management (AM), the different types of AM, and the various definitions and understandings of AM. Secondly, it gives a synopsis of the concept of "learning" in AM and thirdly, it discusses some early proponents of alternative paradigms for energy planning that anticipate the application of AM to the sector. Finally, it provides a brief discussion of the compatibility of AM with the thinking of scholars in the field of evolutionary economics and in the Systems of Innovation framework, which are more suitable for addressing the problem of innovation in the energy technologies used.

One of the forerunners of adaptive management, Aldo Leopold, clearly delineated the distinction between the traditional "science of parts" or conventional approach to management on the one hand, and a more holistic and values-based approach, on the other hand, in his essay entitled "The Land Ethic". In this essay, he laments the lack of an ethic that deals with man's relation to land and to the animals and plants which grow on it (Leopold 1968). He saw a "single plane of cleavage" among many specialized fields such as conservation, where one group sees the land as soil meant for commodity production and another sees it as a biota with a broader function. In forestry or agriculture, for instance, the first group is content to plant trees like cabbages and considers cellulose to be a basic forest commodity, and considers the "poundage or tonnage" of farm crops to be an adequate measure of the food value of those crops (Leopold 1966). The second group, on the other hand, sees forestry as different from agronomy (or agricultural science), tries to manage the natural environment rather than create an artificial one, and worries about the loss of threatened species both on biotic and economic grounds (Leopold 1968). Adaptive management is akin to the second group rather than the first.

In more recent times, adaptive management is being used primarily as an instrument within environmental impact assessment (EIA) and cumulative effects assessment (CEA) studies or as a supplement to these studies in order to help the practitioner reduce the cumulative effects of uncertainties, manage these effects brought about by multiple actors, and inform decision making on practices that can minimize the incremental impacts of proposed actions (Canter and Atkinson 2010). Many definitions of AM exist within the literature that reflect a range of understandings of the concept, due in part to the different applications it lends itself to from natural resource management to project planning and evaluation of environmental impacts, and to project operations and their impacts (Canter and Atkinson 2010). For instance, Hafemeister (2007) defines AM as “implementing policies as experiments”, and as a methodological innovation in resource management that implies revised ends, novel means, and promotes ***learning*** to high priority in stewardship. AM can also be defined as a system of management practices based on clearly identified outcomes, monitoring, and facilitating management changes that will best ensure that outcomes are met, or if not, reevaluated (DOI 2004).

Adaptive management can also be defined in terms of passive AM or active AM. In passive AM, only one course of action is selected and monitoring and management decisions are adjusted relative to the outcomes, while in active AM, multiple courses of action are taken from the very beginning, experimental objectives are clearly defined, and monitoring and subsequent planning decisions are adjusted accordingly (Canter and Atkinson 2010). Furthermore, in active AM, management policies are formulated as experiments that probe the responses of ecosystems as people's behavior in them changes, whereby managers seek to define competing hypotheses about the impact of management activities on ecosystem functions, and design management experiments to test them with several alternative management types (Gregory, Ohlson et al. 2006).

The scope of active AM varies from broad to narrow management problems and although it can deliver more statistically testable information, this information is only as good as the experimental design (Gregory, Ohlson et al. 2006). Since the 1970s, for instance, the management of renewable resources like fisheries and wildlife has often relied on quantitative model building for predicting the responses of alternative harvesting policies, but this effort has not been particularly successful because it had not been able to address uncertainties that cannot adequately be resolved through the traditional methods of scientific investigation (Walters 1986). Indeed, Ludwig, Hilborn et al. (1993) argue that the difficulty in achieving consensus about past events, or making strong predictions about future vents is that it is impossible to perform controlled experiments in large-scale systems, which means that there is large room for diverse interpretations regarding practices that frequently lead to the overexploitation of resources. Furthermore, they claim that scientists are better at recognizing problems than they are at resolving them due to the overwhelming influence of their disciplinary training on their judgment, which tends to militate against the multidisciplinary understanding needed to address such problems, and which is liable to being swayed by political pressures (Ludwig, Hilborn et al. 1993).

In his rebuttal to their article, C.S Holling argued that the authors had an excessively pessimistic view that human shortsightedness usually leads to the overexploitation of resources, and that their caricature of traditional, disciplinary science did not take into consideration evolutionary perspectives and systems approaches that were fundamentally interdisciplinary and considered multiple sources of evidence (Holling 1993). In his earlier work, Holling (1978) had also proposed an approach to bridging the gaps in disciplinary or large-team approaches to environmental assessment and management that relied on workshops of short duration, which consisted of small teams of disciplinary specialists, modeling experts, and decision makers. He was of the persuasion that these workshops were the core of adaptive assessment, and that they were successful at overcoming the natural desire of disciplinary scientists to reduce complexity into smaller and smaller components – a disposition that is not suitable for dealing with management concerns (Holling 1978).

C.S. Holling’s position, notwithstanding, the following points made by Ludwig, Hilborn et al. (1993) do offer an additional perspective on the relative importance of the social, economic and ecological components of sustainability, beyond the mere call for the integration of the disciplines. They suggest that resource problems are more human problems than environmental ones because they were created under different economic, social and political systems; that effective management should also consider human motivation as well as responses as part of the system to be managed; and that actions should be taken even before scientific consensus is achieved (Ludwig, Hilborn et al. 1993). However, based on the views articulated by the scholars cited above, they would most likely agree with the assessment of (Walters 1986) that the design of actively adaptive, probing and deliberately experimental environmental policies should be an essential part of renewable resource management and should address the four following issues: 1.) Bounding management problems in terms of both explicit and tacit objectives, as well as practical constraints on action and other factors that are typically considered in policy analysis; 2.) Formal optimization and mathematical modeling of the dynamic behavior of managed systems in order to identify uncertainties, generate alternative hypotheses, and as a foundation for further learning; 3.) Statistical analysis that can help explain how uncertainties might spread over time with respect to policy choices, that are consistent with experience and offer some direction toward improved productivity ; and 4.) Designing balanced policies that allow for continuing resource production as well as yielding improved understanding and searching for untested opportunities (Walters 1986).

In passive AM on the other hand, managers typically use historical data from a specific area under consideration or comparable areas to develop a "best guess" hypothesis, outcomes are monitored and new information is used to update historical record (Gregory, Ohlson et al. 2006). Passive AM is useful when there is high confidence in anticipated ecosystem response, and is also good when regulatory or institutional constraints are strong so that the range of variations is small (Gregory, Ohlson et al. 2006). In general, though, the traditional understanding is more aligned with active AM, where management necessarily involves the stakeholders in a goal-directed activity that includes various ways of identifying objectives and justifying goals, and that is pluralistic in the modes of expressing the associated social and environmental values (Norton and Steinemann 2001).

The concept of learning is also central to AM. Learning in AM refers to social learning, which explores the way in which human action affects the natural world in unexpected ways, broadens one's awareness of these effects across spatial, temporal and functional scales, and does so in a manner that is governable, though not necessarily orderly (Lee 1993). Given that social learning itself is an outcome of institutions and politics, it can be expected that controversies and conflicts will occur. The latter, in particular, are more likely when there is disagreement among parties, both about beliefs about causation and about preferences about outcomes, and where mere computation, bargaining, and collegial judgment are not sufficient to achieve consensus around decision making (Lee 1993). However, while controversy is a prerequisite for recognizing errors, severe conflicts may undermine the ability to correct those errors, and even though learning can occur during such situations, it is not guaranteed (Lee 1993).

Adaptive management is *learning while doing*, and it acknowledges that time and resources are too short to deter action and acts even without knowing enough (Lee 1999). Social scientists typically emphasize the organizational and human dimensions of *learning while doing*, which usually involves some form of conflict. The degree of conflict, especially political conflict increases as one goes from a controlled mode of learning such as laboratory experimentation to another mode of learning like unmonitored experience, which is casual, as shown in Table 2.1 below.

Table 2.1 Modes of Learning in Adaptive Management. Adapted from Lee (1999)

| **Mode of Learning** | **Type of Observation** | **Type of Knowledge** | **Type of Activity it informs** | **Accumulation into usable knowledge** | **Example** |
|---|---|---|---|---|---|
| Laboratory experimentation | Controlled to infer cause | Replicated for reliable knowledge | Enabling prediction, design, control | Theory building (narrow range of application) | Molecular biology, biotechnology |
| AM (quasi experiments in the field) | Systematic monitoring to detect surprise | Integrated Assessment for system knowledge | Inform model-building to structure debate | Strong inference | Green revolution |
| Trial and Error | Problem-oriented | Extended to analogous instances | Solve or mitigate particular problems | Empirical knowledge | Learning-by-doing in mass production |
| Unmonitored Experience | Casual | Anecdotal | Identify plausible solutions | Models of reality (political) | Statutory Policies |

In addition, organizations can be thought of as representing a working model of a theory that is intended to solve a specific set of problems. However, because reality is often more complex than expected, errors usually emerge, some of which can be resolved by mechanisms that are already anticipated by the underlying organizational theory in a process known as *single-loop* learning (Lee 1993). On the other hand, other problems cannot be resolved by the theory exemplified by the organization, and these require a reexamination of both its routines and purposes in a way that enables a diagnosis of the issues with the theory that lies beneath the practical problems through a process called *double-loop* learning (Lee 1993). Thus, when the conflict associated with learning while doing described above does not damage the institutional fabric, double-loop learning results in an improved theory of reality, whereby the fundamental organizational theory is in closer alignment with the actual system responses. This kind of learning, where theories are tested against management actions and revised in consideration of experience, is required for effective adaptive management to take place (Lee 1993).

## 2.2 Adaptive Management and Energy Planning

The emphasis of AM has typically been on managing ecological systems, but it has also been used to analyze the Northwest Power Act of 1980 in the U.S. in the context of a natural system, namely the Columbia River Basin of the Pacific Northwest (Lee 1993). This established the main precedent for applying AM to energy systems in the U.S. Prior to Kai Lee's publication of this book, however, he had published a book on electric power in the Pacific Northwest in 1980, and had presented a paper to the Northwest Power Planning Council (now the Northwest Power and Conservation Council) in 1982 in which he discussed power planning in the face of uncertainty. The six central issues that lay at the center of the Northwest hydropower debate to develop a regional legislative framework were as follows: 1.) enlarging the regional power supply; 2.) financing of the facilities; 3.) allocation of costs of generation to both wholesale and retail customers; 4.) implementation of energy conservation, 5.) planning for generating reserves, and 6.) revision of governance and administrative arrangements (Lee, Klemka et al. 1980; Lee 1982).

Even though he did not explicitly use the term "adaptive management" in these earlier publications, Kai Lee's methodology reflects the core principles of AM, and the Council would later use the term formally in all its planning documents. In 1996, he appraised AM as an approach to policy implementation and concluded that it had been more influential as an idea than in practice, and that it should be used only after a collaborative structure has been put in place (Lee 1996). He nevertheless emphasized in that paper, that the type of social learning facilitated by AM would likely be of strategic importance in governing ecosystems sustainably

Two other power authorities that have investigated the potential of AM to aid electricity planning include the Tennessee Valley Authority (TVA) and the Glen Canyon Dam in the U.S. In the case of the TVA, its five-year Integrated Resource Plan (2011-2015) provides six scenarios in collaboration with its partners and stakeholders that are intended to meet future energy demand, and address their financial, economic and environmental impacts in the face of uncertainties outside of TVA's control (TVA 2011). The TVA has also put forward a proposal for the Tims Ford Dam in Franklin, Tennessee to redesign its existing Environmental Impact Assessment (EIA) as an adaptive management process to monitor the temperatures and appropriate water flows that aquatic life can thrive in (TVA 2008). The purpose was to improve the habitat conditions of two species identified as endangered by the U.S. federal government, namely the boulder darter fish and the cracking pearlymussel, as well as other species, while balancing other program interests such as flood protection, water supply and quality, recreation and power production (TVA 2008).

The adaptive management program for the operation of the Glen Canyon Dam was established in 1996 through the signing of the Record of Decision for the Glen Canyon Environmental Impact Statement, in order to provide a process and organization to better manage dam operations and protect the resources affected by it in the Colorado River ecosystem (USBR 2001). The guiding principles for designing this AM program and that may be adapted to other hydropower facilities are as follows: 1.) monitoring and research programs should be designed by qualified researchers in response to the needs of management agencies; 2.) there should be a process to communicate the needs of the management agency to researchers; 3.) there should be a forum for transferring research results to management in order to develop consensus on management responses to conditions; 4.) all management programs should be scientifically valid and independently reviewed; 5.) and interested parties in the relevant legislation should have an opportunity for full participation in recommendations and proposals (Wieringa and Morton 1996).

Nevertheless, the idea of an alternative planning paradigm for energy systems themselves had been discussed for some time. One modern concept that offers such an alternative is that of renewable distributed generation (DG), which refers to a set of small-scale renewable energy technologies and approaches to energy management that generate power in close proximity to its point of consumption (Sovacool 2006). These technologies can help reduce greenhouse gases and other harmful byproducts of traditional sources of power such as oil, natural gas, coal or nuclear energy and offer many other advantages in large part due to their flexible nature.

However, the concept of DG is not new and was discussed under the term "soft energy path" in the landmark essay by Amory Lovins entitled "Energy Strategy: The Road not Taken", which offered a radical shift and a mutually exclusive path from traditional, centralized, fossil-fueled generation which he called a "hard energy path" (Lovins 1976). The paper was later expanded into a book entitled "Soft Energy Paths: Toward a Durable Peace", in which he pursues his argument by insisting that the two energy paths are distinguished by their antithetical social implications and provides technical arguments to show that the more socially attractive system is also cheaper and easier to manage (Lovins 1977). Lovins was influenced by the concept of Appropriate Technology, which implies a focus on a type of technology that is usually small scale and enhances the productivity of primary work, but is not overly sophisticated and capital intensive (Schumacher 1993). In a rebuttal to his critics, who accused him of presenting advocacy along with analysis, he argued that it was the results of his own subsequent analyses in the area of energy that ultimately impressed him about the idea (Lovins 1977).

As early as 1960, the late Senegalese Professor Cheikh Anta Diop had proposed an African Energy Doctrine that took into account both renewable and non-renewable resources, ecological considerations, and the technological advances that would be possible in future decades (Diop 1987). He argued that sub-Saharan Africa in particular, would have to find a formula for "energy pluralism" that would harmoniously combine hydroelectric energy, solar energy, nuclear energy, geothermal energy, hydrocarbons (including coal, oil and natural gas), thermonuclear energy (based on heavy hydrogen obtained mainly through the electrolysis of sea water), wind, and tidal energy. His view of hydrocarbons for energy production was that they were highly polluting and would ultimately be depleted, and that given the imminent onset of alternative sources of energy, petroleum products should gradually be relegated to being used only as raw materials for the synthetic chemical industry (Diop 1987).

Twenty-five years later, in 1985, in a keynote address at an international symposium on Science, Technology and Development in Africa that was held in Kinsasha, Zaire (now the Democratic Republic of Congo), Diop cited the early evidence for anthropogenic climate change and pointed out that there would be a shortage of fossil fuels between 2010 and 2020 given the global rate of consumption (Diop 2005-2006). In that lecture entitled *"Le problème énergétique africain"* or "The African Energy Challenge", which was later published as a journal article, he outlined the future potential of clean energy in the form of thermonuclear energy, hydrogen energy or centralized solar power to both serve as alternatives to progressively dwindling fossil fuels and to meet the ecological threat presented by climate change, and also advocated for an interconnected grid on the African continent. However, he argued that it was imperative for African engineers to first master the construction of small hydroelectric dams, bioenergy for rural industrialization and the decentralized use of solar and wind power in order to meet the immediate challenges of healthcare and food security (Diop 2005-2006). Thus, although Diop was conscious of the environmental ramifications of various energy technologies, he did not oppose centralized generation to distributed generation, nor did he oppose soft versus hard energy paths, but rather, he established an order of priority for the existing technology and resource options given the developmental requirements of African people as he saw them at that historical juncture.

## 2.3 Adaptive Management, Learning and Innovation

As discussed in Chapter One, one of the pioneers of the adaptive management framework, C.S. Holling, had argued that learning and innovation are best suited for economics and organizational theory, even though the scope of his analysis was not expanded to encompass these issues (Holling 1995). Similarly, it is interesting to note that the founding theorists of the evolutionary theory of economic change, namely, Richard Nelson and Sidney Winter, also highlighted the challenge of the long-term ecological viability of successful modernization, but had not developed it any further in their account (Nelson and Winter 1982). The more recent theory of “panarchy” provides a framework for understanding and potentially influencing increasingly faster cycles of change in complex systems, and integrates existing theories of complex adaptive systems, organizational theory, economics, evolution and ecology (Gunderson and Holling 2002).

The concept of "*learning*" in the Adaptive Management framework is analogous to that used in the Systems of Innovation Framework because it is grounded in an understanding of evolutionary change in both environmental management and technological innovation. In AM, learning refers to social learning, which explores the way in which human action affects the natural world in unexpected ways, broadens one's awareness of these effects across spatial, temporal and functional scales, and does so in a manner that is governable, though not necessarily orderly (Lee 1993).

The notion of learning-by-doing in economics was introduced by Kenneth Arrow in 1962 to explain productivity growth, whereby a new industrial plant is started and productivity gradually rises as the workers and management learn to operate it, and tackle and solve many of the problems, faults and bottle-necks associated with its productive practices(Andersen and Lundvall 1988). The historical progression of the concept of learning can be shown in the simple schematic below.

*Neoclassical Econ.* ⟶ *Economics of Innovation (K. Arrow)* → *Systems of Innovation*

The concept of learning is central to Innovation Systems thinking, and can be understood as a process of technical change that is achieved by diffusion, the adoption of innovations produced elsewhere, and incremental innovation of acquired techniques (Viotti 2002). Four types of learning can be identified as being crucial to the innovation process, namely, learning by searching, learning by doing, learning by using, and learning by interacting (Kamp, Smits et al. 2004). Learning by searching refers to the systematic search for new knowledge and is synonymous with research and development (R&D). Learning by doing denotes the practical experience or the know-how needed to manufacture a product, learning by using is that knowledge that is acquired by adopting and using a particular product, while learning by interacting occurs through persistent user-producer relations and is required for a successful innovation (Kamp, Smits et al. 2004).

The link between innovation systems and sustainability is an area of inquiry that has become more important in recent years, particularly in light of contemporary concerns about the impact of industrialization on climate change. While the bulk of this kind of research is in industrialized nations because of their technological base, there has also been a push to investigate different pathways that less industrialized countries might employ in an effort to bypass the currently dominant economic development paradigm in favor of a more environmentally sustainable one.

In the context of non-industrialized or late industrializing economies, most of the learning that is tacit and localized knowledge, occurs through the DUI (Doing, Using and Interacting) mode (Lundvall, Vang et al. 2009), thereby connecting the innovation of the user and that of the producer through the flow of goods and services (Andersen and Lundvall 1988). The interactive aspect of learning is dependent on both space and time, and because innovation, strictly speaking, is more like creation than learning alone, Viotti (2002) suggests that the term 'National Learning Systems' should be used in place of 'National Innovation Systems' for those late industrializing economies that are characterized by technological learning rather than innovation per se (Viotti 2002). For these countries, he distinguishes between a passive learning strategy in which the technological effort is mainly targeted at the simple assimilation and absorption of production capability, while an active learning strategy goes beyond the mere absorption of production capability and aims at the mastery of both production and improvement capability (Viotti 2002).

Since its introduction, the Innovation Systems framework has taken two main perspectives. The first is a narrow perspective, which focuses on mapping indicators of national specialization and performance regarding innovation and R&D efforts, while the second is broader, and includes wider considerations such as education, social institutions, macroeconomic conditions, and communication infrastructure, particularly with respect to their impact on the process of learning and competence building (Lundvall, Vang et al. 2009). In the majority of sub-Saharan African countries, for instance, there is a widespread assumption of straightforward links between basic knowledge generation from formal educational institutes to the economic agents that apply this knowledge, which is consistent with the narrow view of IS, and as such, both educational and R&D institutes work in isolation from industry (Adeoti 2002). This situation helps to explain the poor state of industry in the region given the strong evidence of de-industrialization from strong positive growth in the 1960s to weak or negative growth in the 1980s, and a slight increase in the 1990s (Adeoti 2002). From a development perspective, the NSI theory highlights the relevance of several actors, not just the artificial opposition between the market and the state; it focuses on political, institutional and cultural issues in addition to economic ones; directs attention to concrete processes of interactions between organizations and actors; plus, it "is a tool for analyzing concrete aspects of innovation activities in developing countries" (Lee 1999).

Finally, the challenge of sustainable development is requiring scholars to re-assess technological change and adopt broader perspectives, such as extending the framing of the problem from clean technology to industrial ecology, from environmental economics to evolutionary perspectives on environmental innovation, and investigating sustainable transitions in socio-technical regimes (Smith, Voß et al. 2010). Even though the development of innovative capabilities was stressed in critical responses to the report by the Club of Rome in the 1970s entitled "Limits to Growth", and more recent discussions around ecological modernization attempt to decouple economic growth from environmental degradation, some of the important research challenges that are yet to be resolved include how to operationalize these transitions empirically, and how to govern them sustainably, while maintaining a high level of reflexivity (Smith, Voß et al. 2010).

# Chapter Three

## Policy Analysis: Reframing the ECOWAS Strategy

In this chapter, the existing ECOWAS policies and strategies are presented in a consolidated format through what has been described in Chapter One as a "traditional policy analysis". This type of analysis seeks to translate social, economic and political issues into technically defined problems that can be solved through improved administration or program design, in contrast with a more argumentative and deliberative orientation that explicitly tries to integrate both normative and empirical analyses (Fischer 2007). One possible demonstration of the latter type of analysis is described in Chapters Five and Six through the examination of specific energy policy contexts in the U.S. and West Africa respectively, using adaptive management as the lens for framing the multiple and overlapping concerns. The four analytical categories that are used in this chapter to analyze and reframe the existing ECOWAS strategies include a discussion of a stakeholder analysis of the major players in the sector, a review of life cycle assessments of the various technology options for electrification, the expected outcomes of the electricity sector in the region, and an evaluation of the outcomes of the sector using Bardach's typology of evaluative criteria.

### 3.1 Stakeholder Analysis:

The purpose of the stakeholder analysis presented below is to identify, assess and understand the relevant stakeholders with respect to their influence on electricity planning in West Africa. A stakeholder analysis (SA) can be defined as a tool for identifying the opportunities and constraints that make it more or less likely that a particular strategy, policy, or venue will be able to initiate either a belief or a policy change (Weible 2006). In the areas of natural resource management and environmental management where there is a link between economic efficiency, equity and environmental objectives, stakeholder analysis can help respond to the challenge of sorting out the multiple interests and objectives in a given case (Grimble and Wellard 1997).

The five main questions that will be addressed in this section, and that most applications of stakeholder analysis focus on are: 1.) Who are the stakeholders involved? 2.) What are their interests and beliefs? 3.) Who has control over the crucial resources? 4.) Who do they form coalitions with? 5.) What strategies or venues do they use to accomplish the goals they set for themselves? (Weible 2006). Four broad groups of actors or stakeholders can be said to be involved in electricity planning in West Africa, namely, regional organizations, national agencies, international donor organizations, and civil society organizations. It should also be noted here that there are some affected parties that may not be represented explicitly by these four broad stakeholder groups, such as some existing and potential users of electricity. However, because this group is not organized and is difficult to characterize with respect to the five main questions listed above, it is omitted as a well-defined stakeholder grouping. Nevertheless, it is accounted for within the expected outcomes of the electricity sector and the evaluation of these outcomes discussed later in the chapter. Under each stakeholder grouping, I address questions 2 through 5 wherever each is relevant.

*i. Regional Stakeholders:*

The main regional body is the Commission of the Economic Community of West African States (ECOWAS), which has its headquarters in Abuja, Nigeria. It consists of a president, vice-president and seven commissioners who are responsible for different sectors such as the human development and gender departments, the infrastructure department, and the agriculture, environment, and water resources department. An important part of the Commission's mission is to provide support to the fifteen member states to help them build the capacity to implement the regional programs.

The ECOWAS Commission also has a number of specialized agencies with the three of them that are designated for coordinating regional electrification being the West African Power Pool (WAPP), the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), and the ECOWAS Regional Regulatory Electricity Authority (ERRERA), which is the regional body that regulates cross-border interconnections in West Africa. The West African Gas Pipeline (WAGP) project was initiated by ECOWAS to transport natural gas from Nigeria to Ghana, and passing through Benin and Togo, in order to use it for generating electricity there. However, the pipeline is actually owned and controlled by the West African Gas Pipeline Company (WAPCo), which is a limited liability company that owns the WAGP. The WAPCo is managed by Chevron, which is its largest shareholder (36.7%), with the Nigerian National Petroleum Company (NNPC) (25%), Shell Oil Company (18%), and the Takoradi Power Company of Ghana (16.3%) being the other majority shareholders (WAPCo 2012).

There is also a West African Gas Pipeline Authority (WAGPA), which has its own legal and financial autonomy, and whose function is to facilitate regulatory functions on behalf of the four countries involved, and the national and international energy companies. Another important regional institution is the ECOWAS Bank for Investment and Development (EBID) that along with its associated private sector organizations like ECOBANK, helps to fund electrification projects in various countries in the region.

*ii. National Stakeholders:*

The main stakeholders at the national level are the ministries of energy of the various countries, which are often coupled with the ministerial portfolios for mines. Another set of national stakeholders are the state-owned and usually vertically-integrated energy utilities of the various countries, many of which own subsidiaries for the distribution of electricity or for serving transmission functions. Some of these include the Volta River Authority (VRA) of Ghana, and its transmission subsidiary, the Ghana Grid Company Limited (GRIDCO), or the Power Holding Company of Nigeria (PHCN) has several local distribution companies (LDCs) across different parts of the country. Similarly, the "Communauté Electrique du Bénin", which is jointly owned by Benin and Togo, generates or purchases electricity that it sells to its subsidiaries, the "Societé Béninoise d'Energie Electrique in Benin", and the "Compagnie d'Energie Electrique du Togo" in Togo. In Senegal, the Société Nationale d'Electricité du Sénégal (Senelec) is the state-owned utility, which remains responsible for the generation, transmission, and distribution of electricity following two failed attempts to have it privatized in the context of the energy sector reforms that were being implemented in 1999 and 2001 respectively, (Fall and Wamukonya 2003).

The electric utilities listed above are responsible for providing electricity to the 20% of the West African population that has access as discussed in Chapters One and

Three, but in rural areas, where approximately 80% of the population in sub-Saharan Africa lives, the access rate is typically less than 3% (Karekezi and Kithyoma 2002). Part of the reason for this disparity can be explained by the fact that while many urban residents can afford to pay for electricity, most in the rural areas cannot, and so there is a perceived risk of a low financial return on the investment of extending electricity to these areas. Thus, a strong national policy is required to tackle this problem as has already been done in most parts of the world. However, this is not the case in West Africa, where rural electrification is not viewed as a priority, ostensibly in light of more pressing development concerns, with the exception of Ghana, which has 30% rural access, and the Cape Verde Islands.

The government of Ghana, for instance, has a 30-year National Electrification Scheme (NES) that was initiated in 1990 and is intended to achieve universal access by 2020. The policy is intended to reach 80% of its population by 2015 and 100% by 2020, and is designed to provide grid-based electricity to communities that have more than 500 people in them. The government had initially selected 110 communities in the Ashanti and Brong Ahafo regions for its Self-Help Electrification Project (SHEP), which is a part of the NES that would require communities within 20 kilometers of an electrified town to wire at least 30% of their own homes and purchase their own low voltage electric poles in order to qualify for state support for the remainder. (Osabutey 2011). However, the government later obtained a loan from the ECOWAS Bank for Investment and Development (EBID) to absorb that cost. Some estimates suggest that as high as a 72% access rate had been reached as of 2012. Such ambitious projects are the exception rather than the norm in West Africa.

The bold and creative policy initiatives described above can undoubtedly be credited to the political leadership in place in Ghana around 1990, but more importantly, the stability of political power and its steady transfer ensured that the NES continued to be implemented and modified through successive governments until now. Despite the impressive increase in electricity access, the reliability of power for those already connected to the grid has deteriorated in recent years in the form of load shedding actions and increasingly frequent power outages due to the inability to meet the growing demand for electricity. This increased shortfall in electricity generation is due to a number of factors. These include the fact that more people are being connected to the grid and consuming more power at a faster rate than the supply, but also that the water levels in the Volta River, particularly during the drying season, are becoming lower due to the effect of climate change, thereby reducing the maximum amount of power that can be generated from the dams. Ghana also has agreements with neighboring countries to supply them with some of the electricity it generates, which also reduces the amount of power available to its residents.

However, Ghana’s Renewable Energy Act of 2011, which is yet to be passed into law, highlights the need to diversify its energy resource portfolio in order to both increase supply and meet access requirements, but these efforts are still in their initial stages. For its part, the updated master plan of the West African Power Pool projects that solar and wind energy developments in Burkina Faso, Mali, and Northern Nigeria are only expected to come online towards the end of the plan, between 2017 and 2021. Thus, the current reliance on traditional energy sources across the region is a limiting factor in satisfying both reliability and access requirements.

*iii. International Funding Organizations:*

International funding organizations play a large role in the West African electricity sector because they provide the loans for building much of the electricity infrastructure including generating stations and transmission and distribution systems. They also play a significant role in providing technical assistance, which in turn, shapes the projects and policies to a large extent. Nevertheless, it is possible to distinguish between three kinds of funding agencies within this stakeholder group based on the different institutions that fund the WAPP, ECREEE, and small rural projects, respectively.

The first set of funding organizations tends to favor the large scale, centralized generation and transmission infrastructure that sometimes require decades to build, such as large hydroelectric dams, large gas or oil-based power plants. The WAPP's 20-year master plan, for instance, which focuses on large scale generation and infrastructure for the purposes of power pooling, relies on funding from international financial institutions (IFIs) like the World Bank, and organizations like the United States Agency for International Development (USAID) and the European Union's EU-Africa Partnership on Infrastructure. In fact, only approximately 13% of the WAPP's priority projects are locally funded, while the remainder comes from international sources (Pineau 2008).

More specifically, the IFIs are mainly interested in power sector reforms with an emphasis on improving the technical and financial performance of electric utilities through the unbundling of services and the deregulation and privatization of state-owned companies. Although some of these reforms have resulted in a reduction in technical losses and provided a better quality of service to already electrified areas in certain countries, they have had little to no impact on non-electrified areas (Mebratu and Wamukonya 2007). In Nigeria, for instance, critics of the implementation of the reform process have complained that it had neither created a more competitive business environment, nor had it shown any significant improvement in power supply, despite the billions of U.S. dollars that had been spent up till then (Dayo 2008). The failed attempts at privatizing Senelec, the Senegalese national utility cited in the previous section, were due to disagreements between the partners in the purchasing consortium regarding the allocation of shares in the first attempt, and between the bidders and the government itself in the second one (Fall and Wamukonya 2003). In the end, the government stopped the privatization processes and “re-nationalized” Senelec, bought two new generators through loans from regional West African banks, and was able to improve power supply in the immediate period after the end of the privatization efforts (Fall and Wamukonya 2003). In recent years, the Export-Import Bank of China (China Exim Bank) has also provided loans to the government of Ghana that are making it possible for the Chinese company, Sinohydro, to construct the controversial Bui Dam in the Volta River Basin (Hensengerth 2012).

It is also worth pointing out here that even in industrialized countries like the U.S., a number of leading energy scholars have recognized that deregulation neither introduced effective competition, reduced prices, nor introduced innovations, but actually preserved traditional monopoly rights to distribution, thereby discouraging on-site or distributed generation (Casten and Ayres 2007). This was partly due to the fact that there had been an over-reliance on full deregulation as a goal, rather than viewing the substitution of markets for traditional regulation as one choice among many other policy instruments (Lave, Apt et al. 2004; Apt 2005). Thus, there is limited confirmation that deregulation, as the overriding policy promoted by the IFIs, significantly improves the performance of utilities, including in their home countries, and even less evidence that it would help to increase the rate of electrification in non-industrialized parts of the world like West Africa.

A second set of donors is more predisposed to providing funding to established regional or national organizations to fund smaller scale, renewable energy technologies but the amount of financing they offer is still significantly more limited than that of the first group. ECREEE, for example, relies on such donor organizations as the United Nations Industrial Development Organization (UNIDO), which is a co-founder of the center, the Austrian Development Cooperation (ADC), and the Spanish Agency for International Development Cooperation (AECID). According to an ECREEE official, the USAID has also funded the development of the ECOWAS Policy on Renewable Energy that has now been adopted by all the ECOWAS energy ministers, indicating that the first two types of donors are not necessarily mutually exclusive, and that the emphasis should be placed on the relative proportions of the funding allocated to centralized versus distributed renewable energy systems.

Thirdly, there is another kind of donor that can be considered to be non-governmental and that attempts to implement small scale renewable energy solutions, usually in rural areas. One example is the Washington D.C.-based Solar Electric Light Fund (SELF), which has taken solar-powered drip irrigation systems to villages in Benin and Nigeria (Eaton 2012). Another is the UN’s Millennium Village Project, which enlists the services of several NGOs, and is introducing micro-financing for solar lighting to some villages in West Africa.

While it is true that large scale projects are capital-intensive, it is in many instances easier to acquire loans for those, than to get loans for smaller projects that are also cost-prohibitive for the majority of the population. One senior expert at a university-affiliated technology consultancy center in Ghana who has worked on energy issues for many years stated that in his experience, the large scale projects are typically favored by donor organizations. However, even in those cases where smaller scale technologies were supported, their main goal was often the demonstration, testing, and marketability of their preferred products. Furthermore, he stated that there is a tendency for those internationally sponsored projects that do come on the ground to collapse after they are completed, because their employees might be assigned to another country, or the funding may be discontinued.

The energy and technology expert cited above explained that most local banks were not interested in the smaller projects either, possibly due to the risk that they would not be put into productive uses, and because the microfinance loans that they offer are not currently used for energy projects. As a result, he argued that wholesale funding packages, whether domestic or foreign, were not necessarily required, but that an emphasis should be placed instead on building local capacity. This activity, combined with maintenance efforts and more flexible financing approaches would be much more effective at ensuring the sustainability of small projects. Nevertheless, he emphasized that with respect to financing in general, there should be more of an inward focus, that is, within the country, rather than an outward one.

*iv. Civil Society Organizations:*

There are a few NGOs, including internationally-based ones that work on promoting sustainable energy use, mainly in the form of decentralized solutions. However, the low penetration of decentralized renewable technologies such as mini hydro, solar, or wind, which together contribute less than 1% to the energy mix in West Africa, confirms the responses given by most of the interviewees that their impact is still very low. In addition, many of the local NGOs that get involved with energy issues in West Africa tend to do so from the perspective of the social and environmental consequences of large dams for hydroelectric power. A Ghana-based energy expert that was interviewed suggested that strong stakeholder involvement was needed at the planning stage, especially for centralized generation, but that such stakeholders were not usually invited to participate in the early planning.

Two of the three case studies on adaptive management in West Africa in Chapter Six of this dissertation feature two such organizations, namely, the National Dams Dialogue and the Volta River Basin Organization in Ghana, and the Komadugu-Yobe Basin (KYB) Project in Nigeria. In the third case, the Songhai Centre in Benin is actively involved in the development and utilization of biogas-powered electricity, as well as solar energy. It should be noted here that the first two organizations also support the concept of more modular renewable energy solutions as alternatives to what they consider to be inadequately managed large dams. However, the challenge with most of such local groups is that there are not enough of them with the financial means and the technical know-how to implement those kinds of energy projects.

The table below shows the four groups of stakeholders and four of their characteristics with respect to the issue of broad-based electrification. These characteristics are ranked as low, medium or high according to the level of involvement/interest/influence/impact of the stakeholder groups. The source of the information in the table is my assessment of the interview data.

Table 3.1 Characteristics of Electricity Sector Stakeholders in West Africa

| Stakeholders | Characteristics | | | |
|---|---|---|---|---|
| | Involvement in the issue | Interest in the issue | Influence/Power | Impact of actions on the intended beneficiaries |
| Regional Organizations | Medium | High | Medium | Low |
| National Agencies | Medium | Medium | High | Low |
| International Funding Organizations | Medium | Medium | High | Low |
| Civil Society Organizations | Medium | High | Low | Medium |

In Table 3.1 above, the regional organizations only have a "medium" level of involvement in the issue because they are no longer at the beginning stages of planning, and have well formulated plans for both centralized and distributed electrification, but at the same time, those plans are only being implemented to a low extent. They can be said to demonstrate a "high" interest in the issue based on their initiation of new programs and specialized agencies, and the mobilization of funds to support their activities. However, they only have "medium" power because their activities depend on the political support of the member states. Also, most residents of the region are not aware of their activities and have not seen a significant impact from them, thus they have a “low” impact characteristic. In general, they are “supportive” of the issue of broad-based electrification.

The national agencies and donor organizations have a “medium” level of involvement in the issue because they are mainly focused on centralized generation focused around the urban centers and in general, they do not have any bold or ambitious plans for either rural electrification or distributed generation. A West African energy expert with both national and regional experience argued that this was not likely to change unless rural electrification followed an explicit social policy that includes cross-subsidization and private sector investment. The two notable exceptions that would have a “high” level of involvement if assessed separately would be Cape Verde and Ghana, as discussed above.

Civil society organizations only have a medium level of involvement because as explained earlier, most of them face financial and technical limitations in their ability to be more involved in decentralized approaches to electrification, and currently focus on ameliorating the social and environmental consequences of large scale energy production. This also explains their “medium” level of impact on the anticipated beneficiaries. However, through some of their publications and the interviews conducted, they expressed a high interest in the issue. On the other hand, most national agencies and donor organizations have a medium level of interest because they tend to prioritize the centralized generation and transmission infrastructure, while demonstrating lower levels of interest in rural or decentralized electrification. This corresponds to the low impact on the intended beneficiaries by both stakeholders as can be determined by the relatively static rates of access to electricity.

Overall, Table 3.1 suggests that the national agencies and donor organizations have similar characteristics in terms of the roles they play within the power sector and their impact on it because there is a strong correlation between the national policies for electrification and the financing available to fund their implementation. In the cases of the regional organizations and civil society organizations, their involvement and interest in the issue is mitigated by their lower levels of power or influence, which ultimately affects the impact on the people who currently lack access to affordable electricity.

The analysis of the stakeholders presented above has identified the main stakeholders involved in the electricity sector, provided an explanation of their various roles, levels of interest, and has underscored their relative levels of power or influence within the sector. It suggests that because the regional organizations depend on international funding organizations for their initiatives, as well as on the support and decisions made by the member countries, most of which also depend on the same funding organizations in their respective power sectors, these three sets of stakeholders represent a type of coalition. Thus, the relative success of Ghana, for instance, with respect to its increased access rates (a social outcome), can be attributed in part to the fact that it demonstrated a high level of initiative and independence vis-à-vis the other two groups of stakeholders in the coalition. It conceived its own national electrification scheme, is currently implementing it, had made a strong attempt to involve local communities in its Self-Help Electrification Project (SHEP), and has mobilized its own funding both through the state and with the assistance of a regional development bank. This has not been the case in most of the other countries, which have primarily emphasized and invested in the restructuring of the sector in line with the recommendations of the international finance institutions (IFIs), but to the detriment of a socially-motivated policy and at the expense of fostering stronger ties with civil society.

### 3.2 Life Cycle Assessment of Technology Options: A Review

The purpose of this section is to provide a technology assessment of the existing options for electrification in West Africa based on a review of the literature. Although it is a stand-alone assessment, it is a useful addition to the two prior policy-oriented analyses in this chapter in that they all provide specific analytical insights into various aspects of the West African power sector. The review also fits well with the overall theme of the chapter of "reframing" the ECOWAS strategy in the sense that it emphasizes the point made in the introduction to this dissertation that while rigorous, discrete analyses are helpful in making decisions about policy, they do not represent a "final" solution to a given problem unless they become part of a more deliberative process. Furthermore, given that many commentators offer differing interpretations of which technologies are more beneficial than others depending on the point at which they are assessed (either at the end use or some other unspecified set of points), the technology assessment provided here offers a review of a more rigorous approach to comparing these technologies, which is done across their entire lifecycles.

A life cycle can be defined as the total life span that a product goes through from the extraction of the raw material used to produce it, to its manufacture, to its use, and ultimately, to its disposal as waste into the environment (Nieuwlaar 2004). A Life Cycle Assessment (LCA) then refers to the evaluation and analysis of the life cycles of various products. While an LCA is typically limited to environmental issues, the term can sometimes include social and economic considerations as well (Nieuwlaar 2004). However, the LCA is used in this dissertation only in reference to the environmental issues, and is distinguished from the Environmental Impact Assessment (EIA) referred to in subsequent chapters because of the emphasis of the LCA on the products themselves. The results obtained from a levelized cost of electricity (LCOE) analysis, which is a standard analytical technique for comparing the life cycle costs of different systems (Byrne, Zhou et al. 2007), are presented in the modeling exercise in Chapter Four, which compares five different scenarios for distributed electrification in West Africa. Furthermore, the net present costs (NPC) of the optimized technology options presented in that chapter are the same as the life cycle costs according to developers of the HOMER software package that I used.

In principle, an LCA evaluates complete chains, that is, it provides a cradle-to-grave analysis that includes both the number of processes the product had to go through, and the number of environmental impacts. These impacts are usually related to energy conversion systems, and typically include acidification, climate change, human toxicity, ecotoxicity, and the depletion of primary energy carriers (Nieuwlaar 2004). It should be noted, however, that not all LCAs for the same nominal system are necessarily comparable and there may be wide variations due to differences in the methodological approach, the particular data set used, or even the research questions that initiated the results (Soimakallio, Kiviluoma et al. 2011). For example, in the assessment of greenhouse gas (GHG) emissions associated with grid-based electricity, the perspectives of an attributional life cycle assessment (ALCA) describes environmentally relevant physical flows of a past, current, or future product. However, those from the more market-based consequential life cycle assessment (CLCA), which describes how those flows would have been or will be changed in response to decisions, are reported to provide different findings than those of the ALCA (Soimakallio, Kiviluoma et al. 2011).

Given that a contribution to the type of methodological debate highlighted above is beyond the scope of this dissertation project, the goal of this section, then, is simply to use examples from the peer-reviewed literature to demonstrate the types of materials and pollutants, as well as their general orders of magnitude that should be accounted for in selecting a particular energy system. The current section sheds more light on the LCA characteristics of the main energy systems used in West Africa for both centralized and distributed generation (DG). The centralized generation technologies are primarily based on hydropower, oil, and natural gas, as mentioned in Chapter One, while the DG technologies include diesel generators, solar photovoltaic panels, wind turbines and biomass gasification systems. With respect to LCA, the difference between fossil fuel-based energy systems and non-fossil-based sources, including nuclear energy, is that in the former, the main environmental impacts mainly come from combustion and their associated waste and flue gases, while in the latter, the impacts are based on the environmental profile of the materials used in their manufacture (Nieuwlaar 2004).

The life cycle assessment described below of a 3 kW community hydroelectric power system that was juxtaposed with assessments of a diesel generator and electricity from the grid in Thailand can be compared favorably to the West African context. In that assessment, Pascale, Urmee et al. (2011) demonstrated that when placed in a rural setting, the 3 kW run-of-the-river generator produced better environmental and financial outcomes than both a diesel generator and grid-based power generated from natural gas (72%), coal (15%), and large dams (7%). Their result was in contrast to most other LCA studies that had previously shown that smaller hydroelectric generators have a higher environmental impact per kWh than larger grid-based systems, which shows the site-specific dependence of some LCAs due to the use of different assumptions and considerations. Some of the inputs to the hydropower system located in rural Thailand included the associated components of the 3 kW pump itself, namely, the motor, capacitors, and induction generator controller, and other inputs such as PVC pipe parts or galvanized steel parts, all measured in kilograms. In addition, the hydropower system outputs included forest use change ($m^2$), potential river bed use change ($m^2$), and the lifetime energy available at the connection to the buildings (kWh) among others (Pascale, Urmee et al. 2011).

Furthermore, Pascale, Urmee et al. (2011) measured seven different categories and indicators in their life cycle impact assessment (LCIA), which is a phase of the LCA that seeks to evaluate the magnitude and significance of potential environmental impacts on a product. These included the global warming potential (GWP) over 100 years, the acidification potential (AP), the eutrophication potential (EP), the ozone layer depletion potential at steady state (ODP), the petrochemical ozone creation potential (POCP), the abiotic depletion potential (ADP), and the primary energy demand from both renewable and non-renewable resources (PED). The unit of measurement of the last indicator is in kWh, but the first six indicators are measured in g/kWh because 1 kWh is the functional unit or reference unit for the quantified product performance that is typically used in most LCA studies on electricity generation (Pascale, Urmee et al. 2011). Six of these categories except PED are consistent with the nine recommendations of the U.S. Environmental Protection Agency (EPA) for assessing energy systems with the three additional categories being ecotoxicity, human toxicity, and land use (Nieuwlaar 2004).

Table 3.2 below shows the total environmental impacts of the community hydroelectric generator across its entire life cycle, as well as the corresponding impacts from a diesel generator and grid-based power, where the indicators for the latter two technologies are represented as multiples of those of the hydro-powered generator, which is used as the baseline. It covers six steps within the product system including the intake or dam, the penstock or the pipe that takes the water to the turbine, the turbine itself, the transmission line, the control house, and ultimately, the distribution component, with transmission having the highest impact across most of the categories.

Table 3.2 Total LCIA Results for 3 kW Community Hydroelectric Generator Compared to Diesel and the Grid (Pascale, Urmee et al. 2011).

| Category or Indicator | Hydroelectric generator (g/kWh) - baseline | 7 kV A diesel generator | Grid-based power connection |
|---|---|---|---|
| ADP (g Sb-e) | 0.264 | x(45) | x(23) |
| AP (g $SO_2$-e) | 0.372 | x(9) | x(29) |
| EP (g $PO_2$-e) | 0.030 | x(13) | x(14) |
| GWP (g $CO_2$-e) | 52.7 | x(27) | x(18.5) |
| ODP (g R11-e) | $3.13 * 10^{-6}$ | x(1.5) | x(4) |
| POCP (g ethene-e) | 0.030 | x(9) | x(22) |
| PED (kWh) | 0.150 | x(46) | x(24) |

Many studies that perform LCAs of renewable energy technologies tend to focus almost exclusively on greenhouse gas (GHG) emissions such as $CO_2$, $CH_4$, and $N_2O$ as the measure of environmental impact, because these gases have the greatest impact on climate change, and because alternative energy industries consider this to be the most relevant metric that can prove that their technologies have a lower impact on global warming (Fleck and Huot 2009). In this regard, the LCA approach is advantageous because it helps to determine whether or not this assertion is verifiable, and serves to clarify the extent to which RETs may outperform conventional technologies from an environmental point of view. It does this by including both the emissions from upstream processes such as energy resource extraction or the technology production, which are usually neglected in other analytical methods, and the downstream emissions from the electricity generation stage. While the GHG emissions from fossil fueled-technologies mostly come from downstream processes, and make up more than 75% of the direct emissions from the plant, emissions from renewable energy technologies are dominated by the upstream processes that usually account for more than 90% of their cumulative life cycle emissions (Weisser 2007)

A study on the greenhouse gas based LCA of biofuel and bioenergy systems found that electricity generated from biomass residues, which is also modeled in Chapter Four of this dissertation, typically does not increase pressures on the environment because those wastes are not specifically produced to be used as energy resources (Cherubini, Bird et al. 2009). There are exceptions to this, however, such as if the removal of residues from land depletes the soil nutrients or reduces the carbon stored in carbon pools like soil or dead wood, and secondly, if the creation of a market for residues leads to the production of the original commodity, such as timber. In terms of GHG emissions per unit of output of energy, the emissions that result from either firing biomass directly or from the biogasification of biomass are shown in comparative perspective with other selected renewable energy and fossil fuel technologies in Table 3.3 below.

Table 3.3 GHG Emissions from Electricity for Selected Energy Technologies. Adapted from (Cherubini, Bird et al. 2009).

| Energy technology system | GHG emissions (g $CO_2$-eq./MJ)[3] |
|---|---|
| Biomass | 15 – 30 |
| Biogas | 15 – 65 |
| Wind | 1 – 10 |
| Hydro | 0.5 – 10 |
| Solar PV | 15 – 40 |
| Coal | 300 – 500 |
| Oil | 200 – 300 |
| Natural Gas | 100 – 200 |

The data in Table 3.3 show that the GHG emissions from biomass and biogas-generated electricity are larger than those of wind and hydropower, and are comparable to those of solar PV. However, the emissions from fossil-fueled generators are higher than

[3] The equivalent carbon dioxide ($CO_2$-eq.) unit represents the amount of a given greenhouse gas (GHG) or mixture of GHGs that would cause the same level of radiative forcing, that is, that would have the same global warming potential (GWP) as an equivalent amount of $CO_2$.

those from renewables by an order of magnitude. The ranges in data for a given technology can be attributed to datasets from different sources because different LCAs rely on life cycle inventories with different input values, and can be explained by the different allocation rules applied to bioenergy systems because many of them produce different material products and co-products relating to either electricity or heat, or both (Cherubini, Bird et al. 2009).

Finally, a direct comparative study between the life cycles of a wind turbine and a solar PV module by Zhong, Song et al. (2011) also showed that the former has a lower GHG emissions than the latter, but it also demonstrated that wind turbines have a lower environmental impact across all the assessment categories. The authors found that the larger amount of fossil fuels used in the energy-intensive manufacturing process of solar PVs had the most significant impact on the difference in GHG emissions between the two technologies. However, they also argued that even though it would be beneficial for energy from solar PVs to be used to help power the assembly phase, a bigger challenge would remain in the disposal phase because only small quantities of the recycled waste can currently be reaped from solar PVs as compared to wind turbines. In the case of the wind turbine system, Fleck and Huot (2009) found that the most emission intensive process was in the production of the battery banks, followed by the tower production, and thirdly, battery bank delivery, with the turbine production process itself and all other processes accounting for only 8% of the system's GHG emissions.

### 3.3 Outcomes:

As I outlined in Chapter One, the main goals or outcomes of the electricity sector in West Africa can be classified as social (support for basic services such as health, education and clean water), industrial (improved mechanization, agricultural productivity, communication and resource transformation capability), environmental (reduced pollution) and national (national autonomy) or regional (Pineau 2002). In this section, I reframe the existing regional energy policies to fit into the typology of outcomes presented above, which will then serve as the goals against which the evaluative criteria are subsequently assessed.

One of the main sources of the explicitly stated outcomes of the electricity sector in West Africa is the 2003 ECOWAS Energy Protocol, which establishes a legal framework that seeks to use complementarities and mutual benefits between countries to stimulate long-term cooperation in the energy sector, increase investment in the sector, promote energy trade in the West Africa region (ECOWAS 2003). The other sources of policies that fit into the different classes of outcomes are taken from the 2006 White Paper for a Regional Policy on Energy Access (ECOWAS 2006) and the 2011 master plan of the West African Power Pool (Tractebel 2011). These outcomes, which are the expected results of the electricity sector are briefly described below.

i. *Social goals:*

There is no direct mention of social goals in either the ECOWAS Energy Protocol or the master plan, with the exception of a statement in the latter document that states that the environmental and social impacts had been evaluated for the priority projects of the

WAPP, and that the additional costs relating to environmental constraints had been incorporated. The main document that focuses on social goals is the White Paper for regional energy access that was adopted in 2006, which is a guiding policy document for ECREEE, the renewable energy center, but is not a binding document for any parties.

The White Paper states that poverty eradication is at the heart of both the national and regional policies of ECOWAS member states, and cites energy poverty as a dimension of poverty that is defined by a lack of adequate access to sufficient, affordable and environmentally sustainable energy services (ECOWAS 2006). It emphasizes the strong connection between energy and human development, and cites the low levels of access to modern energy, and the continually growing inequality between urban and rural areas. Its suggested strategies for tacking these issues include the mobilization of soft loans and funds for projects aimed at extending energy services to poorer areas, the sharing, promotion and dissemination of regional experiences regarding the supply of such areas with energy, and the promotion of the local production of energy goods and services.

*ii. Industrial goals:*

The only significant reference to industrial goals across the three documents that are the main sources for this section was in the White Paper, which calls for the establishment of an investment and innovation fund, and asks for the raising of financial support to implement 200 renewable energy demonstration projects. More importantly, it calls for a support fund, also known as patient capital, which can not only promote local manufacturing in the area of end-use energy equipment, but for energy-efficient technologies and renewable energy technologies as well.

*iii. Environmental goals:*

The environmental goals of the region are addressed in Article 19 of the Protocol, which requires all contracting parties to respect all international agreements regarding the environment to which they are signatories. It states that the parties should endeavor to minimize all environmental impacts occurring as a result of their activities in a cost effective manner. In addition, Article 43 requires all the parties to cooperatively develop energy efficiency policies, laws and regulations, and to assess the energy, environmental and economic impacts of the actions taken.

*iv. Regional goals:*

A number of different articles within the ECOWAS Energy Protocol underscore the stated regional goals with respect to energy. For instance, Article 8 within the Energy Protocol addresses technology transfer and requires contracting parties (both regional and international) to promote access to the transfer of energy technologies on a non-discriminatory basis, and to eliminate existing obstacles in the transfer of these technologies. In addition, Article 18 requires the contracting parties to recognize the sovereign rights of the various states over their own energy resources, to promote the development and exploration of energy resources, to observe the environmental regulations of the areas under exploration, and to allocate authorization licenses and contracts to prospect for, or extract energy resources in a non-discriminatory manner.

The four expected outcomes of the electricity sector in West Africa explicitly described above re-emphasize the multidimensional nature of this sector, and are supported by various regional policy documents. However, citing them specifically under these categories of outcomes allows them to serve as benchmarks both for assessing the efforts and progress made in the sector, and as a set of targets that should be aimed at by the relevant stakeholders.

## 3.4 Evaluative Criteria

The purpose of this section is to provide an *ex post* evaluation of whether or not, and to what extent, the policies of the main electric power planning organizations, namely, the WAPP, ECREEE, and the national planning agencies or ministries, have met their stated goal of broad based electrification in a manner that is consistent with the wider outcomes of the sector as outlined in Section 3.1. These policies include centralized generation (CG) and power pooling, renewable energy and energy efficiency, and electricity access and power supply stability.

The evaluation criteria are organized around Bardach's typology, which defines four broad categories that are typically used to evaluate the goals of a given policy. These include technical feasibility, economic and financial possibility, political viability, and administrative operability (Patton and Sawicki 1993). I add a fifth criterion to these four, which is environmental sustainability, because this it is a critical one, particularly for the power sector. The evaluation is primarily based on interview data provided by electricity sector policy actors in West Africa and other written documentation, and is informed by the prior analyses present in this chapter, that is, the stakeholder analysis, and the life cycle assessment review.

More specific criteria are evaluated under each of the broad categories, which are selected, where applicable, from one or more of the six different types of decision criteria as presented by Dunn (2009). These include effectiveness, adequacy, efficiency, equity, responsiveness, and appropriateness. Following the discussion about whether or not the different criteria have been met by the planning agencies, the section then presents a scorecard evaluation of the selected criteria. Each of these criteria is ranked with decreasing degrees of success according to the three following measures: “criterion has largely met expected outcomes”, “criterion needs to be addressed more seriously to satisfy expected outcomes”, and “very difficult to address criterion to satisfy expected outcomes”.

1. Technical Feasibility:

The criterion of technical feasibility helps to clarify whether or not the existing energy resources and electricity infrastructure are able to satisfy the current demand in the region. With respect to the resources for centralized generation, natural gas and hydropower were the preferred resources for electrification that were identified by the WAPP in its original master plan (Nexant 2004). It stated in that document that West Africa had enough natural gas reserves to fulfill all its needs for the next 20 years. In the revised master plan, it forecasts a more diversified portfolio including coal, heavy fuel oil (HFO), diesel oil, as well as renewable energy resources such as solar, wind, or biomass energy, as long as the project has a minimum installed capacity of 150 MW (Tractebel

2011). In Chapter Four of this dissertation, I demonstrate the technical potential for solar, wind and biomass energy to meet all the electricity requirements of the region, and therefore, if one includes the non-renewable resources, it is evident that technically, there are sufficient energy resources in the region for present and future electrification.

In terms of energy technologies, there is no indigenous manufacturing base for centralized technologies, and despite existing plans to manufacture solar PV modules in Senegal and Nigeria (discussed in further detail in Chapter Seven), I could find no evidence that any DG technologies are currently being produced in West Africa. Thus, while both technology classes are technically feasible, they both also depend on technology transfer from industrialized nations and other industrializing nations for their implementation. With respect to the ongoing implementation of these options, the sub-criteria of effectiveness and adequacy described below shed more light on the current status of the plans.

*i. Effectiveness:*

As stated above, while the existing energy resources are able to satisfy the current demand in the region, the existing electricity infrastructure is not sufficiently capable of doing so. However, in terms of achieving the vision articulated by the official agencies, it is necessary to note that both the WAPP and ECREEE represent the institutional framework for coordinating a coherent plan for the regional electric system. The practical implementation of this vision, then, also depends on the individual electricity sectors of the member states. With respect to centralized generation, the contracting company that authored the updated 2011 master plan stated that the reason for developing a new version was that in the original master plan commissioned in 2004, there had been a large gap between its objectives and their implementation due to the slow development of power systems at either the national or regional level. However, more specific explanations for the lack of implementation were revealed in interviews with some WAPP officials. These reasons are listed below:

- The energy crisis that lasted from 2006 to 2008 negatively impacted the implementation, and insufficient rainfall also negatively affected the anticipated power production from the hydroelectric dams.
- There is a need to balance transmission and generation components of the electric power system that still had not been achieved. This is important because one of the biggest drivers to stable frequency is adequate generation, and new reserves or spare generation needed for self-correction was yet to be secured.
- High voltage transmission lines were not supposed to go through population areas but while the routing had originally been done by a French engineering firm, it was now being done by a Korean environmental firm that was better equipped to avoid population centers and environmentally sensitive areas.
- Even though the construction of the West African Gas Pipeline (WAGP) from Nigeria all the way to Ghana, and passing through Benin and Togo, had already been completed, there was still no gas flowing through it due to some technical difficulties such as a high level of moisture in the pipeline and loss of pressure in certain segments. It has also been delayed by the political and social instability in the Niger Delta, which produces the natural gas.

For distributed generation, which is mainly discussed in the 2006 ECOWAS White Paper, the renewable energy agency, ECREEE was only inaugurated in May 2010, and is not intended to implement projects but to create an enabling environment for them to be developed. An ECREEE official informed me that the framework took some time to be put in place because operating rules have to be fair to everyone including investors, but that the necessary communication with member states and capacity building efforts by focal institutions in the region were already underway.

*ii. Adequacy:*

This criterion determines to what extent the core problems listed above as barriers to effectiveness have been addressed by the policies of the various agencies. With respect to the problems faced in the implementation of the WAPP master plan, the energy crisis may have subsided, but the rainfall is still insufficient and unpredictable due to the variability in patterns that is likely caused by climate change. However, there is an ongoing rehabilitation of existing hydroelectric dams in Ghana and the new Bui dam is currently being constructed. Secondly, there is still a need for adequate electricity generation to help stabilize the transmission frequencies. Thirdly, I cannot confirm whether the routing of transmission lines away from population centers and other sensitive areas has improved, but the West African Gas Pipeline is still not fully functional due to recurring technical problems according to its own website.

In terms of the implementation, the launching of the ECOWAS Renewable Energy Foundation (REF), which is managed under ECREEE, has helped to achieve the implementation of small projects based on the white paper, such as the support of small biomass energy projects in rural and peri-urban areas. Calls for new proposals have also been made that according to an ECREEE official, are intended to have larger projects being made operational within a year or two.

2. Economic and Financial Possibility:

*i. Cost effectiveness:*

This criterion seeks to determine whether or not the objectives of the policies have been achieved at a minimum cost. As indicated in the stakeholder analysis in Section 4.2 above, there is currently very little adoption of renewable energy in West Africa and so this criterion has not been satisfied. However, *ex ante* analyses that precede policy adoption can help to predict whether this criterion can be met in the future. For instance, an appraisal of a microgrid project in rural Senegal presented in Chapter One showed that when negative environmental externalities from fossil fuel use are considered, the levelized cost of electricity LCOE of off-grid wind turbines and solar PV are cheaper than both grid connected electricity and diesel generators (Thiam 2010). Similarly, the results of the modeling exercise presented in Chapter Three demonstrates that based on current prices, distributed renewable electricity based on solar, wind, and biomass energy can be less expensive than diesel generators in areas that are not connected to the grid.

*ii. Efficiency:*

Under this criterion, the goal is to determine whether or not the human, financial and technical resources have been used in the most cost-effective and efficient way. This criterion is difficult to assess in a quantitative manner due to the lack of access to official data regarding those resources. However, the fact that, in general, the power sector reforms that were undertaken by most countries have not been successful as discussed in the stakeholder analysis, suggests that this criterion has not been met. The specific example about the high financial costs invested in Nigeria compared to the low benefits received by the majority of the population helps to emphasize this point. The exceptions to this pervasive situation are Ghana and Cape Verde.

3. Political Viability

*i. Appropriateness:*

This criterion is intended to determine whether or not the policies and strategies of the planning organizations have been appropriate for meeting the requirements of the overall policy context. For the WAPP, the fundamental question of whether power pooling is the best approach for West African countries at this early stage in the development of its power sector has been addressed by Pineau (2008). Similarly, the appropriateness of the power sector reform undertaken by the individual countries has also been addressed by Mebratu and Wamukonya (2007). For example, are the efforts being made toward power sector reforms such as vertical unbundling of generation, transmission and distribution, or horizontal unbundling (that is separation into smaller utilities) appropriate to the overall policy context? Are the few existing DG programs that are being run suitable to the context?

*ii. Responsiveness:*

In terms of responsiveness, the policies cannot yet be said to have been responsive to the needs and requirements of the target group of the policies. This is because there is little to no public participation in the original preparation of the regional or national plans outside of the role of the already elected officials. However, the regional officials interviewed stated that within the limits of their mandates, they would soon begin outreach programs to sensitize the people of the region to the work that they are doing.

*iii. Equity:*

With respect to the criterion of equity, the current policies in place by either the regional or national authorities cannot be said to have helped to reduce income-based or vertical inequalities, nor can they be said to have reduced inequalities among various demographics. This is because, as discussed in the above criteria, the policies have not yet been fully implemented, and to the extent that they have, the impact is still low.

4. Administrative Operability

*i. Authority:*

The criterion of authority seeks to determine whether or not the implementing organization has the authority to convert policies into programs or make incremental changes. While the national governments have the full authority to convert policies into programs and to change them, the regional organizations are limited in their authority because they are not sovereign in their decision making capability, and depend on the cooperation and support of the national governments in order to implement any policies.

*ii. Capability and Organizational Support:*

The challenge here is to assess whether the financial and technical staff of the various implementing ECOWAS agencies have the necessary skills to implement the policies as well as the infrastructure to do so. Irrespective of whether centralized generation or DG is chosen in any given situation, the creation of local human resources capacity to maintain and generate future power is an important consideration. While this is mentioned as a policy objective in the White Paper, it is not addressed in either the original or the updated master plans.

However, a review of the discussions surrounding various African power pools reveals that the institutional capacity of countries and the integration environment are typically taken for granted and therefore largely ignored (Pineau 2008). Furthermore, the projects under the original master plan, for instance, were largely formulated by non-African bodies, primarily Purdue University's Discovery Park, the U.S.-based firm, Nexant Corporation, and Electricité de France as explained by Pineau (2008). That master plan was conceived and designed by a Nexant - Electricité de France technical team consisting of 10 persons, who were assisted by three African counterparts whose roles were marginal and included participating in project meetings, undergoing training on the Nexant approach to modeling and financial analysis and facilitating data gathering in their zones.

Although this situation is due to the nature of the funding, it is nevertheless important to underscore the point that since the conceptualization, formulation and implementation of the plan were being controlled with only minimal local participation, the adoption or indigenization of technology becomes very difficult thereby undermining organizational capability. At the time of my interviews with the WAPP officials, the updated master plan that was contracted to Tractbel Engineering, a Belgian firm, had not yet been issued, and I am unable to confirm whether the make-up of the technical teams has changed significantly since the days of Nexant.

In the case of ECREEE, the United Nations Industrial Development Organization (UNIDO) was its co-founder, is currently a technical partner, and is considered a donor at the same time. In addition, ECREEE is connected to a national focal institution in each member state and has started capacity needs assessments in all fifteen- member states, which has resulted in a solar roadmap and a bioenergy strategy being drawn for the region. The agency is also continuing with resource assessments for solar, wind, biomass as well as "small" hydro projects, which typically have less than 10 MW in capacity. In general, data access in the region is very difficult, but commissioned assessments are being done by three universities in the region, namely, the University of Cape Verde, the Kwame Nkrumah University of Science and Technology in Kumasi, Ghana, and the "*Institut International d'Ingénierie de l'Eau et de l'Environnement"* (International Institute for Water and Environmental Engineering) in Ougadougou, Burkina Faso.

*iii. Institutional commitment:*

The criterion of institutional commitment asks whether or not the top administrators and other office and field staff are committed to policy implementation. Just as in the criterion of "authority" above, the questions of commitment also ultimately rests on the national governments because the regional organizations mainly carry out what has been agreed upon by the different countries. In the case of the national governments, they cannot be said to have a high commitment to electricity policy commitment. Outside of the two highly performing countries, Ghana and Cape Verde, only in Nigeria and Senegal is there a consistent discourse by the national governments on their initiatives to solve the problem of electrification. Nevertheless, their weak performance compared to the leading countries in this effort, strongly suggests that the full institutional commitment is still lacking. Furthermore, a Ghanaian energy expert stated that his country's successful electricity policy was based on an explicit social policy, which involves the use of political capital and will since the private sector is not naturally inclined to invest in rural electrification.

Based on the interviews with the WAPP and ECREEE officials, both sets of officials expressed a commitment and optimism that their respective agencies' policies would be implemented. One ECREEE official in particular stated that renewable energy had been his lifelong passion; he focused on it during his university education and throughout his career, indicating a strong alignment between his personal motivation and the agency's policy. However, ECREEE's institutional commitment can be said to higher in part because the smaller scale renewable technologies are closer to the implementation stage than the longer term infrastructure and regulatory regime needed to make the power pooling arrangements work.

5. Environmental Sustainability

*i. Energy Technology:*

The energy technologies adopted by in the revised master plan of the WAPP are based on a diversified portfolio of resources including hydro energy, natural gas, coal, heavy fuel oil (HFO), diesel oil, solar, wind, and biomass energy. However, there is no assigned order of priority, unlike in the adaptive scheme for energy planning presented in Chapter Four, and in fact, renewable energy resources other than hydro power are expected to come online much later within the plan. The three non-hydro renewable projects cited in the revised master plan are a 150 MW solar project in Burkina Faso, which is expected to be commissioned in stages between 2017 and 2019, another 150 MW solar project in Mali, which is expected to be commissioned between 2019 and 2021, and a 300 MW wind farm in northern Nigeria, which is expected to be commissioned in stages until 2021 (Tractebel 2011).

The assessment of these technologies based on the review of the life cycle assessments (LCA) in Section 3.3 confirms that on the basis of a cradle to grave analysis, the fossil fuel-based technologies not only emit a higher amount of greenhouse gases (see Table 3.3), they also have a greater environmental impact by virtue of their higher acidification potential (AP), eutrophication potential (EP), ozone layer depletion potential (ODP), petrochemical ozone creation potential (POCP), and abiotic depletion potential (ADP) as shown in Table 3.2. The technologies being developed by ECREEE are based on energy efficiency and renewable energy and so, based on the life cycle of those technologies, they have lower environmental impacts. However, the national energy ministries generate less than 1% of their electric power from renewable energy resources other than large hydroelectric systems, and their generation profiles generally resemble those of the region as a whole. Thus, their environmental impact is essentially identical to that of the region as described above.

*ii. Environmental Policies:*

The environmental policies of the WAPP are based on Environmental and Social Impact Assessments (ESIAs) and hydropower plants have Resettlement Action Plans (RAPs) that explain the legal and administrative framework under which projects are supposed to operate. They also describe the project site, the natural environment in the area, human environment, cultural heritage, and they provide an economic evaluation of the environmental costs. However, the involvement of the local populations in planning is sometimes lacking as exemplified by the management of the dams in the Volta River Basin described in Chapter Six. On the other hand, the selection of a Korean firm with better environmental credentials than a French one to do the transmission line routing through population centers displays a sensitive and reversible environmental policy.

The environmental policies or the national governments are also consistent with those of the WAPP with respect to the large projects. In the case of ECREEE, it does not have an explicit environmental policy but its calls for proposals frequently require that the projects not compromise the environment in order to be approved. Table 4.2 below shows a scorecard evaluation of the policies of the three many implementing institutions in West Africa.

Table 3.4 Scorecard Evaluation of Electricity Policy Options in West Africa

Outcomes →

Criteria ↑

| | CG & Power Pooling Policy (WAPP) | Renewable Energy and Energy Efficiency Policy (ECREEE) | Electricity Access & Power Supply Stability (National Ministries) |
|---|---|---|---|
| **Technical Feasibility** | | | |
| • Effectiveness | Z | Y | Z |
| • Adequacy | Z | Y | Z |
| **Economic and Financial Possibility** | | | |
| • Economic efficiency | Z | Y | Z |
| • Cost effectiveness | Z | Y | Z |
| **Political Viability** | | | |
| • Appropriateness | Z | X | Z |
| • Responsiveness | Y | Y | Z |
| • Equity | Z | X | Z |
| **Administrative Operability** | | | |
| • Authority | Z | Y | X |
| • Capability and organizational support | Z | Y | X |
| • Institutional commitment | Y | X | Z |
| **Environmental Sustainability** | | | |
| • Energy Technologies | Y | X | Y |
| • Environmental Policies | Y | X | Y |

KEY: X = "criterion has largely met expected outcomes"
Y = "criterion needs to be addressed more seriously to satisfy expected outcomes",
Z = "very difficult to address criterion to satisfy expected outcomes"

In conclusion, this chapter has provided a stakeholder analysis of the major players in the sector, an overview of life cycle assessments of various energy technologies, outlined the expected outcomes of the electricity sector in West Africa, and has given an evaluation of the main policy options for electrification in the region. Based on the analyses presented in the chapter, the evaluation suggests that with respect to the specified criteria, ECREEE satisfies more of them than either the WAPP or the national ministries. The latter two have a similar evaluation profile in which most of the criteria need to be addressed more seriously or are very difficult to address. In addition, while the national ministries have a greater authority, capability, and the organizational support needed to implement their policies than the WAPP does, the interview data suggests that the WAPP officials have a higher institutional commitment to implement the policies than do their government counterparts within their respective mandates.

An important lesson that can be drawn from the analyses in the chapter across all the categories of criteria is that there should be a greater sense of responsibility and accountability for the implementation of electrification policies on the part of the national and regional organizations. Furthermore, the chapter has demonstrated that in the relatively successful countries, in particular, Ghana, the adoption of a more diverse set of policy instruments and approaches, and a more intensive engagement with civil society were favorable conditions for both the expansion of access to electricity and the improvement of the performance of utilities.

# Chapter Four

## Adaptive Energy Modeling and Analysis

The aim of this chapter is to present a quantitative analysis of some of the technological, economic and environmental implications of extending electrification to the people in West Africa who are not currently connected to the grid. In this context, I attempt to implement the planning philosophy first outlined by Lee (1982), which established the basis for applying Adaptive Management to the management of energy resources at the Northwest Power and Conservation Council (NPCC). Although this planning approach was originally conceptualized from the perspective of a large scale, centralized, regional power system in the U.S., I employ the main notions and some of the procedures that are applicable to the vastly different setting in West Africa where the centralized generation and transmission infrastructure is limited. Overall, the chapter provides an analysis that addresses research questions one and two, which are outlined in Chapter One, from a quantitative vantage point.

In his discussion paper, entitled "The Path Along the Ridge: Planning in the Face of Uncertainty", Dr. Kai N. Lee, who was then a member of the Council, identified two main types of uncertainties facing the region. The first was the uncertainty of demand forecasting, and the second was that of planning for conservation and new generating resources. He then proposed a more flexible plan to manage the risks arising from these uncertainties, which consisted of choosing a combination of resources and programs that would yield a regional power system that was cost-effective and resistant to risk, in contrast with the established utility practice of deterministic planning at that time (Lee 1982).

The main policy issues surrounding the debate on power planning in the Pacific Northwest in the 1980s have been outlined in Chapter One of this dissertation. More specifically, the eight principles suggested by Lee (1982) that were drawn from the Pacific Northwest Power Act, and which offer a coherent approach to regional risk planning in the face of pervasive uncertainty are listed below:

1.) Instead of deterministic planning, a regional risk-management process that stresses flexibility and resilience should be put in place.

2.) As an alternative to relying on a most-likely demand forecast, the planning process should make the region ready to meet a wide range of loads in all the years included in the plan.

3.) Due to the difficulty of forecasting the demand for power, the planning process should shift the burden of risk from individual project proponents to the region as a whole. This would help to insure the entire region from the heavy financial losses that could result from either building too much power generation capability or too little.

4.) The fundamental priority for resource planning should be explicit and should involve a hierarchy: First should be conservation and energy efficiency, which would serve as an additional resource, followed by renewable resources, resources that utilize waste heat, and lastly, all other resources.

5.) There should be an institutional structure for decentralizing the implementation of a centrally written plan.

6.) The regional plan should search for a cost-effective combination of conservation and resources that can provide planning flexibility instead of the conventional bias toward economies of scale in power generation. For instance, when total costs are essentially equal, small projects are preferable to large ones, projects that can be halted, slowed or reversed should be preferable to inflexible ones, and those that can be completed on short notice should be prioritized over those with long lead-times.

7.) The complications associated with licensing, financing and institutional change should require the planning process to develop a planning schedule that reflects the fact that there will be slower load growth when the real rates of electricity are rising.

8.) The additional complexity of augmenting the hydroelectric system with thermal generation or introducing renewables into the grid should be seriously considered during the planning process.

The present chapter focuses on demonstrating the feasibility of the flexible planning approach for the case of distributed generation of energy in West Africa, given that there is no regional forecasting plan in place that includes off-grid areas. Distributed generation (DG) here refers to those small-scale electrical power generation technologies that provide electric power at, or adjacent to a load site, whether directly connected to a customer's facility, to a distribution system, or both (Borbely and Kreider 2001). These small-scale technologies typically generate power on the order of 10kW to 50 MW in close proximity to the end user, and may include renewable systems such as solar panels, biomass power plants or wind turbines, non-renewable systems such as natural gas turbines or diesel generators, and combined heat and power systems (CHP), which produce heat and electricity from the same fuel source (Sovacool 2008). The chapter then illustrates models of how this flexible planning approach might work in West Africa for biomass, solar and wind energy.

One distinction between the conventional utility forecasting approach and the more flexible methodology described by Lee (1982) is that in the former, the goal is to estimate the future electricity demand as accurately as possible, while in the latter, a much broader range of loads is adopted rather than aiming for a "single best forecast" that is based on an assumption of perfect foresight. For instance, even today, many utilities commonly make low, high and intermediate forecasts, based on different assumptions about the consumer response to rate changes, as well as different demographic variables, and they then select the intermediate forecast as the planning target. However, in the face of uncertainty, there is not likely to be sufficient information to choose this intermediate forecast as the actual demand may lie anywhere within the lower and upper bounds of the forecast.

In terms of economics, the distinction is that the flexible risk management approach does not minimize short-run costs, and that a diversified portfolio of projects can significantly lower costs compared to a least-cost investment that turns out to have been based on erroneous assumptions. The main planning concept that offers flexibility is that of the "resource option", which is an acquisition contract backed by the Northwest Power Act that guarantees that a given resource exists and is available, but explicitly allows for regional control over the magnitude as well as the timing of the project.

Chapter Five of this dissertation on “Adaptive Management and Energy Policy in the U.S.A” goes into greater detail as to how modern regional planning agencies in the U.S. such as the Tennessee Valley Authority (TVA) and the Northwest Power and Conservation Council (NPCC) model prospective demand under various conditions, futures and scenarios.

Three of the main principles for managing risk out of the eight that were outlined in Lee’s discussion paper, which are also described above, are operationalized to form the basis of the work presented in this chapter. The first (Principle #2) requires that a wide range of loads be included in the planning process rather than forecasting the most likely demand. The second (Principle #4) is related to the establishment of an order of priority for resource planning in order to minimize cost, which was required by the 1980 Regional Power Act in the Pacific Northwest. This priority should first be given to conservation and energy efficiency, second to renewable resources, third to resources that utilize waste heat or combined heat and power (CHP), and last, to all other resources. The third priority, CHP, would ideally be taken up by industries in the region, while the fourth, “all other resources” include the primary sources in the centralized master plan of the West African Power Pool (WAPP) other than hydroelectric power, and diesel, which is used to power generators either where there is no grid access, or as a source of back-up power. It should also be noted here that ECREEE adopted an energy efficiency policy in 2012 to track and adopt energy savings along with the energy access initiatives in West Africa. However, since this initiative is new and the survey data on the use of appliances, retrofits, or the implementation of building codes in not yet available, I focus in this chapter on calculating some estimates for the second priority, that is, renewable resources, given that access is the more critical factor facing the non-electrified areas in the region.

The third principle (Principle #6) that I rely on is that as an alternative to the traditional bias toward economies of scale in power generation, planners should consider the following factors: 1.) they should look for cost-effective combinations of resources and conservation that could provide planning flexibility; 2.) pick those projects that are available on short notice over those with long lead times if they are equally costly; 3.) choose small projects over large ones; and 4.) select programs that can be slowed, stopped, or reversed, as these are likely to be more useful than those that imply rigid commitments (Lee 1982). This principle offers a key guideline for applying adaptive management thinking to electricity planning in a West African context, particularly in rural and peri-urban areas, where a piece-meal approach would provide a contrast to deterministic regional planning for the purpose of increasing the rates of both policy and technological learning. More specifically, I use the "component sizing" procedure to tailor or scale the various distributed generation (DG) technologies to the level of electricity demand that is needed or that can be afforded at a particular time. Thus, component sizing in the DG approach is a critical instrument for providing planning flexibility.

The chapter first presents a quantitative representation of the current demand and supply or power in West Africa as provided by the authorities of the West African Power Pool (WAPP). I then provide an estimate of both the theoretical potential and a more operational or practical potential for distributed renewable electricity from waste biomass, solar and wind energy, based on the available meteorological data and explicit assumptions applied to a spreadsheet model. Using the component sizing procedure described above, I further demonstrate how solar photovoltaics, wind turbines, biomass gasification generators, and their associated components such as batteries, charge controllers, inverters, or gasifiers, can meet the basic electricity requirements of individual households in non-electrified areas. The basis for modeling these minimum requirements is drawn from the electrification experience of South Africa which increased its electrification rates from about a third to over 80% within a period of less than ten years (discussed further in Chapter Seven).

One of the policy innovations that led to the rapid electrification rate in South Africa was the implementation of a Free Basic Electricity (FBE) Policy, which required that every indigent or poor household be provided with 50 kWh a month free of charge (Bekker, Eberhard et al. 2008). Some provinces have raised this figure to 100 kWh, but certain environmental groups are lobbying for the FBE to be raised to 200 kWh, either through grid-based electricity or through distributed resources such as solar home systems (SHSs) for remote areas (Earthlife Africa 2010). Finally, the chapter presents an analysis of the comparative costs of renewable electricity in a setting with little or no grid access, when compared to the more widely available diesel generator sets, through simulations with the Hybrid Optimization Model for Electric Renewables (HOMER) software package.

## 4.1 Status of Power Demand and Supply in ECOWAS

The most recent data for electricity generation in West Africa by the WAPP were publicly made available in 2010 but the data on the actual electricity generated dates to 2007, with “best forecasts” for subsequent years. The figures are primarily from centralized generation, since electricity from distributed generation (whether from fossil fuels or renewable energy) is considered to be negligible in the region and is not yet tracked in most countries. Although the data from 2007 are not recent, their use can be justified for the purpose of this analysis if we consider that Nigeria, which generates nearly 75% of the region’s electricity (see Table 4.1 below), acquired just under 3500 MW of capacity between 1987 and 2007, but no new capacity has been added since 2007 (Ekpo 2011).

Similarly, in Ghana, the second largest producer, the increase in total production of approximately 3,000 GWh from 2007 to 2010 (GEC 2012), neither significantly alters the regional output nor the proportion between the countries. For this reason, I employ the regional figures supplied by the WAPP across the board for consistency. Table 4.1 below shows the electricity produced by country and by source in 2007.

Table 4.1 Total Electricity Generated (GWh) in 2007 (WAPP 2010)

| | Hydro | Thermal | Import + Others | Total |
|---|---|---|---|---|
| Benin | - | 115 | 585 | 700 |
| Burkina Faso | 81 | 468 | 139 | 688 |
| Cape Verde* | - | - | - | 280 |
| Côte d'Ivoire* | 1,433 | 4,128 | - | 5,561 |
| Gambia | - | 170 | - | 170 |
| Ghana | 5,615 | 2,769 | 629 | 9,013 |
| Guinea | 473 | 167 | - | 640 |
| Guinea Bissau | - | 16 | - | 16 |
| Liberia | - | 12 | - | 12 |
| Mali | 667 | 197 | 2 | 866 |
| Niger* | - | - | - | 280 |
| Nigeria | 9,725 | 27,645 | 1,000 | 38,370 |
| Senegal | 267 | 1,533 | - | 1,800 |
| Sierra Leone | 25 | 32 | - | 57 |
| Togo | 172 | 76 | 522 | 770 |
| Total | | | | 59223 |

*Note: No data for Cape Verde and Niger was provided by the WAPP and therefore the numbers for "Total Electricity Generated" were based on the electricity generation data reported for the earliest year, which was 2009, by the U.S. Energy Information Administration (EIA). Also, the numbers provided for Côte d'Ivoire by the WAPP are the same from 2004 to 2007 most likely due to the political unrest that occurred in the country and that overlaps that period.

While Table 4.1 above shows the portion of the demand that was met in 2007, Table 4.2 shows the amount that was unmet based on the forecast for that year. It should be noted here that the "unmet" demand here only refers to the demand in the grid-connected areas that was not satisfied. Thus, the figures for the "unmet" demand can be considered to account for the amount of power that even many of those who are connected to the grid failed to receive, an occurrence that is not unusual in the region.

Table 4.2 Met versus unmet demand of electricity (GWh) in 2007 (WAPP 2010)

| | Met | Unmet | Forecast |
|---|---|---|---|
| Benin | 660.7 | 59.3 | 720 |
| Burkina Faso | 688 | 184.1 | 872.1 |
| Cape Verde* | 260 | 63.3 | 323.3 |
| Côte d'Ivoire* | 3004 | 723.3 | 3736.3 |
| Gambia | 170.2 | 198.8 | 368.97 |
| Ghana | 7773 | 1892 | 9665 |
| Guinea | 860 | 143 | 1003 |
| Guinea Bissau | 16 | 78 | 94 |
| Liberia | 16 | 124 | 140 |
| Mali | 841 | 109 | 950 |
| Niger * | 740 | 97 | 849 |
| Nigeria | 38370 | 43098 | 81468 |
| Senegal | 1800 | 180 | 1980 |
| Sierra Leone | 56 | 354 | 410 |
| Togo | 673.9 | 96.1 | 770 |
| Total | 55928.8 | 47408.9 | 103350 |

*Note: The data for Cape Verde, Côte d'Ivoire and Niger was not provided by the WAPP and therefore the numbers for the "met demand" were based on energy consumption reported for the earliest year (2009) by the U.S. Energy Information Administration (EIA). The forecast for Niger was then extrapolated from that of Benin because they are both net importers of electricity with a similar consumption pattern, while those of Cape Verde and Côte d'Ivoire were extrapolated from that of Ghana because they are all net electricity producers with similar levels of electrification and consumption.

I then estimate the total demand shortfall if the entire population had access to electricity and received it consistently. I assume the same per capita electricity consumption of each country for those who do not have access to the grid as well, and add the "unmet" demand of those who had grid access but did not receive sufficient power in order to obtain the total demand shortfall. The formula below describes how the total demand shortfall was obtained and Table 4.3 shows the estimated total demand shortfall by country in 2007.

Total demand shortfall = Met demand * (% of population without access / % of population with access) + unmet demand

Table 4.3 Total demand shortfall (GWh) in 2007 (WAPP 2010)

| | Met | Unmet | Fraction without electricity access | Total Demand Shortfall |
|---|---|---|---|---|
| Benin | 660.7 | 59.3 | 0.75 | 2041 |
| Burkina Faso | 688 | 184.1 | 0.9 | 6376 |
| Cape Verde* | 260 | 63.3 | 0.3 | 175 |
| Côte d'Ivoire* | 3004 | 723.3 | 0.53 | 4111 |
| Gambia | 170.2 | 198.8 | 0.92 | 2156 |
| Ghana | 7773 | 1892 | 0.46 | 8513 |
| Guinea | 860 | 143 | 0.8 | 3583 |
| Guinea Bissau | 16 | 78 | 0.89 | 208 |
| Liberia | 16 | 124 | 0.97 | 641 |
| Mali | 841 | 109 | 0.83 | 4215 |
| Niger * | 740 | 97 | 0.91 | 7579 |
| Nigeria | 38370 | 43098 | 0.53 | 86366 |
| Senegal | 1800 | 180 | 0.58 | 2666 |
| Sierra Leone | 56 | 354 | 0.95 | 1418 |
| Togo | 673.9 | 96.1 | 0.8 | 2792 |
| Total | 55928.8 | 47408.9 | -- | 132840 |

The remainder of the chapter then seeks to employ the flexible planning methodology outlined above in order to determine a feasible range of the total demand shortfall that can be met through distributed renewable resources, and in a cost-effective manner.

## 4.2 Estimation of Renewable Energy Resources in West Africa

### 4.2.1 Biomass Energy

The objective of this section is to analyze the potential of crop wastes to meet some of the energy requirements for each of the ECOWAS countries based on the dominant cash crops they produce. In its efforts to promote projects for renewable energy, the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) published a Regional Bioenergy Strategy Framework in March 2012 in order to promote bioenergy development in the region, both for liquid fuels and for electricity (ECREEE 2012). The ECOWAS Renewable Energy Facility (EREF), managed by ECREEE, also approved forty-one grant proposals for small and medium-sized renewable energy projects in August 2012 that included five biomass gasification projects for electrification. While forecasts of electricity generation from biomass and other renewable resources are yet to be made public by the West African regional bodies, peer reviewed publications do offer assessments of the existing energy potential from agricultural resources, forestry resources, or urban, industrial, and other wastes in selected African countries.

For instance, Duku, Gu et al. (2011) have estimated most of the biomass potential in Ghana, and have calculated the energy potential from agricultural residues by multiplying the total mass produced of a given residue with the lower (or net) heating value or energy content of that residue in MJ/kg. The present analysis is consistent with the ECOWAS initiatives cited above, but also goes beyond the mere estimation of the technical potential of biomass energy to demonstrate a set of more realistic and flexible scenarios under which this energy might actually be converted into usable renewable electricity in the region.

One of the main energy and environmental problems in Africa is the widespread harvesting of wood resources for use as cooking fuels by poor households, although a few countries like Senegal and Botswana have now introduced subsidies that allow most of the poor to transition to gas for cooking (Prasad 2008). Because the economy in most African countries is based on agriculture, energy production from agricultural residues can, in principle, provide a consistent source of energy. An often cited example of such a source which is very promising in the U.S. context is the use of corn stover, that is, the stalks and leaves excluding the grain, for ethanol production. Since it is already available in the same areas that produce corn grain, it is accessible to plants that produce ethanol from corn starch (USDOE 2001), thereby reducing the travel time, costs and energy used in transportation.

In China, scientists have recently developed a method of producing clean biogas fuel from rice crop stems and leaves (straws), crop wastes that are usually left behind after harvesting and later burned, thereby releasing carbon dioxide into the atmosphere (Hepeng 2008). Biomass burning from the combustion of wood and agricultural residue in open fields has also been reported to be one of the main sources of trace gases and aerosols in the tropics (Mead, Khan et al. 2008). In Africa, it has led to a 4-5 fold increase of methyl halide emissions from 1950 to 2005 and is expected to double over the next 25 years due to population growth (Mead, Khan et al. 2008).

We can therefore assume that corn, rice and other cereals such as sorghum or millet, widely grown in Africa for food, could be used in a similar manner. Another important advantage of these sources is that it does not significantly change the place orientation of farmers who already cultivate these crops and should provide added income to the farmers while having little or no effect on prices or on greenhouse gas emissions. The harvesting of corn stover must nevertheless be carried out adaptively to ensure that there are no problems with erosion or soil quality (USDOE 2001; Graham, Nelson et al. 2007) but in those cases where the wastes are routinely burned, this would seem appropriate. If we apply this idea to crops that are produced in West Africa, we can estimate the potential for electric power generation from crop wastes by using the U.S. corn stover model.

However, I only model non-food crops or cash crops that are produced in West African countries in this analysis for two reasons. The first is that these crops already serve a commercial function and electricity production is more likely to be readily accepted as adding value to the enterprise. The second reason is to avoid food versus fuel controversies that may arise if I attempted to model electricity production from food crops that are supplied from subsistence or semi-mechanized farming. Although food crop wastes need not be excluded as a source of electricity in principle, any such projects could pose significant conflicts of interest unless they are embedded within a framework of prior and ongoing stakeholder consultations that are transparent.

In order to assess the electric power generation from these crop wastes, two important metrics that have been used to calculate the amount of residue that could be collected sustainably are:

*i.* *The Residue Coefficient (CR):*

This represents the ratio of the dry weight of the crop residue to the total weight of the initial product or crop. Table 4.4 below shows residue coefficients for various crops. Another nomenclature that can be found in the literature is the Residue to Product Ratio (RPR) which is the same as the CR used here (Duku, Gu et al. 2011).

Table 4.4 Residue Coefficients (CR) for various crops

| Grains and Beans (Dry weight residue/grain ratio) | Stems and Nuts |
|---|---|
| • Corn (stalk, cob) = 1.0:1<br>• Soybean (stems) = 1.4:1<br>• Rice (straw, husks) = 1.7:1<br>• Cocoa beans = 0.731:1 | • Manioc (stems, branches) = 0.8:1<br>• Bagasse = 0.3:1<br>• Peanuts = 0.3: 1<br>• Cashew Nuts = 0.3:1 |

Source: (Lora and Andrade 2009)

*ii. <u>The Residue Harvest Index:</u>*

This represents the percentage of crop residue that can be sustainably removed after harvesting. It must be considered that removal may cause an increase in water and wind erosion, reduced crop productivity and a depletion of soil nutrients. Under the current rotation and tillage practices in the U.S., the amount of corn stover that can be collected has been estimated by

$CQ_{c,r,t}$ = $Stover_c$ – Max $constraint_{c,r,t}$, (Graham, Nelson et al. 2007)

Where

$CQ_{c,r,t}$ = Amount of stover collected per hecatare in county c

$Stover_c$ = amount of stover (Mg $ha^{-1}yr^{-1}$). left in the field

Max constraint represents the amount of stover (Mg $ha^{-1}yr^{-1}$) left in the field that meets all erosion, moisture and equipment constraints in county c, under rotation, r and tillage, t practices.

The tilling practices referred to in the description of the Residue Harvest Index (RHI) above include mulch tillage (which requires more stover to be left on the soil to preserve its nutrients) and no tillage conditions. The more highly erodible the land is, the less potential it has as a source of sustainable stover biomass, and the less tilling is carried out, the more stover can be collected (Graham, Nelson et al. 2007). Furthermore, when stringent water erosion constraints are assumed, the collectable stover supply decreases significantly irrespective of tillage assumptions. For instance, regions that do not have a certain amount of rainfall were left out of the analysis.

Based on the current practices of corn production in the U.S., sustainable stover production is less than 28% especially under stringent conditions, but up to 75% can be removed inexpensively while taking into consideration wind erosion, soil erosion, moisture and nutrient loss. (Graham, Nelson et al. 2007). In the state of Iowa, a study showed that 50% of stover could be removed for mulch-till acreage and 67% for no-till acreage, given a weighted average value of 57% (USDOE 2001). Based on the range of sustainable tilling practices cited above, three different scenarios have been analyzed in this chapter for residue harvest indices (RHI) of 30%, 50% and 70%.

The crop wastes that I use to estimate electricity generation mainly include the pods and husk of cocoa beans, the shells of groundnuts and cashew nuts, as well as sugarcane bagasse, which is the fibrous tissue remaining after the sugarcane juice is extracted. Bagasse, for instance, is typically used to satisfy the heat and electricity requirements employed in processing, but the conversion efficiency of combustion processes is typically very low, which makes gasification technology a clean and attractive alternative (Filippis, Borgianni et al. 2004). It has been reported that in Mauritius that sugarcane cultivation occurs for six to nine months in a year and so a coal plant or another source of power must be used for the remaining three to six months (Deepchand 2005). Since this country has the most proven and advanced cogeneration from bagasse program in Africa, the assumption of six months was made in the calculations for all the countries in West Africa that could adopt similar programs in the future.

The use of a biomass gasification generator with an approximate rated power or installed capacity ranging anywhere from 10 kW to 36 kW, a dedicated biomass power plant of 30 MW, or ideally a small biomass integrated gasification combined cycle station (BIGCC) with a power rating of about 50 MW can all be used in a distributed form for clusters of households, larger communities of small farmers (the majority) or large plantations that grow these crops. The agricultural residues from groundnuts, cashew nuts, and cocoa beans are harvested during seasons of varying lengths of a few months to year round cultivation. Table 4.5 below shows the quantities of the two leading cash crops, where applicable, that are produced in each country in West Africa according to statistics provided by the United Nations Food and Agricultural Organization (FAO).

Table 4.5 Quantity of Cash Crops Produced in West Africa in 2010 (FAO 2012)

| Country | Cash Crop A | Cash Crop B | Quantity A (million metric tons) | Quantity B (metric tons) |
|---|---|---|---|---|
| Benin | Groundnuts w/ shell | Cashew nuts w/ shell | 0.11 | 0.07 |
| Burkina Faso | Sugar cane | Groundnuts w/ shell | 0.46 | 0.34 |
| Cape Verde | Sugar cane | | 0.03 | N/A |
| Cote d'Ivoire | Sugar cane | Cocoa beans | 1.7 | 1.2 |
| Gambia | Groundnuts w/ shell | | 0.14 | N/A |
| Ghana | Cocoa beans | Groundnuts w/ shell | 0.63 | 0.53 |
| Guinea | Groundnuts w/ shell | Sugarcane | 0.29 | 0.28 |
| Guinea Bissau | Cashew nuts w/ shell | Groundnuts w/ shell | 0.09 | 0.07 |
| Liberia | Sugar cane | Cocoa beans | 0.27 | 0.01 |
| Mali | Sugar cane | Groundnuts w/ shell | 0.36 | 0.3 |
| Niger | Groundnuts w/ shell | Sugarcane | 0.41 | 0.21 |
| Nigeria | Groundnuts w/ shell | Sugarcane | 2.6 | 1.4 |
| Senegal | Groundnuts w/ shell | Sugarcane | 1.3 | 0.84 |
| Sierra Leone | Groundnuts w/ shell | Sugarcane | 0.09 | 0.07 |
| Togo | Cocoa beans | Groundnuts w/ shell | 0.10 | 0.05 |

### 4.2.2 Estimation of Electricity Potential from Biomass

Assuming a traditional biomass power plant or a biomass integrated combined cycle plant, the net efficiency of the plant is given by

$$\eta = \frac{P_{net}}{\dot{Q}}$$ (Kehlhofer, Hannemann et al. 2009)

(Equation 3.1)

where

$P_{net}$ = Power output at the high voltage terminals of the step-up transformer, and

$\dot{Q}$ = Heat input to the power plant (MJ/s) or the mass flow of the fuel multiplied by the lower heating value or energy content as used here.

The electricity that can be generated from a given mass of agricultural residue can then be determined from:

$$Electricity\ Generated\ \ (GWh) = P_{net}(GW) * \text{hours of operation}$$

(Equation 3.2)

$$= [\eta * \dot{Q}] * \text{hours of operation}$$

$$= [\eta * (\text{m} * \varepsilon * \text{CR} * \text{RHI})/\tau_{yr} * \text{CF}] * \text{hours of operation}$$

Where

m = the mass of the harvested crop (kg)

CR = Residue Coefficient

RHI = Residue Harvest Index

ε = Energy density of crop waste such as shell (MJ/kg)

CF = Capacity Factor of plant = ~ 80%

η = Average plant efficiency = ~ 33.33 %

$\tau_{yr}$= seconds in a year = 31536000 s

Hours of operation = 8760 hrs/yr

Hours of Operation = 4380 hrs/yr because while sugarcane can be cultivated and the plant run for 6 to 9 months in the year (Deepchand 2005), I assume 6 months for all the crops.

In order to demonstrate this calculation for Benin, which is the first country alphabetically in the ECOWAS region, we have:

Mass (m) of groundnuts with shell = 117000 metric tons;

CR of groundnuts or peanuts (Table 4.4) = 0.3:1

Energy content (ε) of groundnuts = 18.9 MJ/kg

Mass (m) of cashew nuts with shell = 69700

CR of cashew nuts (Table 3.3) = 0.73:1

Energy content (ε) of cashew nuts = 23.6 MJ/kg

For a Residue Harvest Index (RHI) of 30%, the total fuel input from crop wastes, $\dot{Q}$ (MJ/s), that goes into the power plant is calculated as:

$$\dot{Q}_{total} = (\mathrm{m} * \varepsilon * \mathrm{CR} * \mathrm{RHI})/\tau_{yr}$$

$$\dot{Q}_{total} = \mathrm{RHI} * \left[(\mathrm{m} * \varepsilon * \mathrm{CR})_{groundnuts} + (\mathrm{m} * \varepsilon * \mathrm{CR})_{cashew\ nuts}\right]/\tau_{yr}$$

= 0.3*[(117*10$^6$ kg *18.92 MJ/kg *0.3) + (69.7*10$^6$ kg *23.6MJ/kg *0.73)]/ $\tau_{yr}$

= 0.3*[664 TJ + 1203 TJ]/ $\tau_{yr}$= 560 TJ/$\tau_{yr}$

$\dot{Q}_{total} = (\mathrm{m} * \varepsilon * \mathrm{CR} * \mathrm{RHI})/\tau_{yr}$ = (560 TJ / 31536000 s)

= 18 MJ/s = 18 MW

The generation capacity, $P_{net}(GW) = \eta * \dot{Q} * CF$ = 0.33 * 18 MW * 0.8 = 4.7 MWe

Finally, assuming that this kind of power can be generated consistently during a 6 month harvesting period,

$Electricity\ Generated\ \ (GWh) = \ P_{net}(GW) * \text{hours of operation}$

= 0.00469 GW * 4380 hours = 20.54 GWh

The demand forecast in Benin in 2007 was 720 GW (See Table 4.1) and the total demand shortfall was calculated to be 2041.4 GWh (See Table 4.3)

Therefore, the percentage of the demand forecast that can be met through distributed generation of biomass energy from two crop wastes for a Residue Harvest Index (RHI) of 30% is: (20.54/720)*100 = 2.85% ~ 3%. This result can be seen in Table 4.6 below.

And the percentage of the total demand shortfall that can be met through distributed generation of biomass energy from two crop wastes for a Residue Harvest Index (RHI) of 30% is: (20.54/2041.4)*100 = 1.01% ~ 1%. This result can be seen in Table 4.7 below.

Thus, I have demonstrated how the numbers for Benin in Table 4.6 and Table 4.7 below for a 30% RHI were calculated. This model was developed in a spreadsheet and the estimates for all the other countries and for the three scenarios (RHI = 30%, 50%, 70%) were obtained.

Table 4.6 Potential Electricity Generation (GWh) from Cash Crops

| Country | Electricity Potential (GWh) - 30 % RHI | Electricity Potential (GWh) - 50 % RHI | Electricity Potential (GWh) - 70 % RHI | Percentage of total demand Forecast (30 % RHI) | Percentage of total demand Forecast (50 % RHI) | Percentage of total demand Forecast (70 % RHI) |
|---|---|---|---|---|---|---|
| Benin | 20.5 | 34.2 | 47.9 | 3% | 5% | 7% |
| Burkina Faso | 41.3 | 68.9 | 96.4 | 5% | 8% | 11% |
| Cape Verde | 1.3 | 2.1 | 2.9 | 0.4% | 1% | 1% |
| Cote d'Ivoire | 178.6 | 297.7 | 416.8 | 5% | 8% | 11% |
| Gambia | 8.6 | 14.3 | 20.1 | 2% | 4% | 5% |
| Ghana | 81.3 | 135.5 | 189.7 | 1% | 1% | 2% |
| Guinea | 30.7 | 51.2 | 71.7 | 3% | 5% | 7% |
| Guinea Bissau | 17.5 | 29.1 | 40.7 | 19% | 31% | 43% |
| Liberia | 12.3 | 20.5 | 28.6 | 9% | 14% | 20% |
| Mali | 32.1 | 53.5 | 75.0 | 3% | 5% | 8% |
| Niger | 36.3 | 60.5 | 84.8 | 5% | 8% | 11% |
| Nigeria | 237.7 | 396.2 | 554.7 | 0.3% | 0.5% | 1% |
| Senegal | 123.6 | 206.0 | 288.4 | 6% | 11% | 15% |
| Sierra Leone | 9.5 | 15.9 | 22.2 | 2% | 4% | 5% |
| Togo | 11.5 | 19.2 | 26.9 | 2% | 3% | 4% |
| Total | 884.0 | 1473.3 | 2062.6 | 1% | 1% | 2% |

Table 4.7 Potential Electricity Generation from Cash Crops as a Percentage of the Total Demand Shortfall

| Country | Percentage of total demand shortfall (30 % RHI) | Percentage of total demand shortfall (50 % RHI) | Percentage of total demand shortfall(70 % RHI) |
|---|---|---|---|
| Benin | 1% | 2% | 2% |
| Burkina Faso | 1% | 1% | 2% |
| Cape Verde | 1% | 1% | 2% |
| Côte d'Ivoire | 4% | 7% | 10% |
| Gambia | 0% | 1% | 1% |
| Ghana | 1% | 2% | 2% |
| Guinea | 1% | 1% | 2% |
| Guinea Bissau | 8% | 14% | 20% |
| Liberia | 2% | 3% | 4% |
| Mali | 1% | 1% | 2% |
| Niger | 0% | 1% | 1% |
| Nigeria | 0% | 0% | 1% |
| Senegal | 5% | 8% | 11% |
| Sierra Leone | 1% | 1% | 2% |
| Togo | 0% | 1% | 1% |
| Total | 1% | 1% | 1% |

Table 4.6 shows that the percentage of the demand forecast that can be met through biomass energy in West Africa varies significantly from one country to another

based on the data for crop wastes that was used, and the assumptions of the model. At a Residue Harvest Index (RHI) of 30%, six countries could contribute 5% or more of their projected demand through biomass energy, while if the RHI went up to 70%, eleven countries could surpass this contribution. Guinea Bissau, Liberia and Senegal are three of the countries that could lead the region in implementing biomass energy projects, while Cape Verde, Nigeria and Ghana, would have low penetration rates of bioenergy because Nigeria and Ghana have a large demand compared to the other countries and Cape Verde produces a very low amount of cash crops. With respect to the total demand shortfall, Table 4.7 shows that Côte d'Ivoire, Guinea Bissau and Senegal have the potential of contributing close to 5% or more of electricity from biomass to meet this demand based on the modeling exercise presented above, but across the entire region this contribution would be about 1%.

A few final points to note are that first, the crops used in this analysis are not exclusive and many other types of agricultural residues may be used in the same manner. Secondly, I only assume six months of power generation (4380 hours) because of the seasonal nature of the crops, but if a combination of other crop residues can be used as substitutes in adjoining seasons, then theoretically, the contribution of biomass energy to electrification could be double the results that I have shown here.

### 4.2.3 Solar Energy

In this section, I analyze the potential of solar energy to address the electricity access requirements of the region, and to contribute to reducing the unmet demand. Solar energy technologies can be either solar thermal systems, which focus sunlight on a fluid to produce steam that can in turn be used in a turbine to generate electricity, or solar photovoltaics (PV), which convert sunlight directly into electricity. This section only analyzes the energy potential from solar home systems (SHSs), which constitute the majority of such installations that are promoted Africa, and include the PV modules, batteries, a charge controller, and an inverter and in some cases. An inverter is only needed if one intends to use appliances that operate with Alternating Current (AC) or one plans to buy and sell electricity from the centralized grid, which is not yet the case in West Africa.

However, the prospective impact of the SHSs on rural and peri-urban areas have been highly contested by some researchers who have advanced the view that they are not cost effective with respect to the low levels of service they can provide (mainly lighting and low voltage appliances) and due to the opinion that scarce government funds would be better spent on reforms of the conventional public power sector until such a time as PV technology becomes more mature and affordable (Karekezi and Kithyoma 2002; Wamukonya 2007). The approach taken in this chapter, and in the dissertation more generally, is intended to tackle these types of concerns through an emphasis on experimentation and on “learning”, which is the subject of Chapter Six.

The regional strategy for the deployment of solar energy across West Africa is the ECOWAS Solar Energy Initiative (ESEI), which began in 2010, and includes a short-term plan (2010-2012), medium-term plan (2013-2015) and a long-term plan (2016-2020) for its widespread utilization. As part of the short term plan, a solar atlas and resource database for West Africa has been prepared and political targets for solar energy have been adopted, such as 40% of the 500 MW EU-Africa energy partnership target, among other initiatives. The medium term goals include commissioning the first solar electric plant of greater than 10 MW by 2015 and establish more reliable regional information systems about solar energy utilization, while the long term goals include the development of larger scale solar projects (>200 MW), and the launching of regional manufacturing centers for solar energy systems and components. With respect to the on-going short term plan, the ESEI reported that it has conducted a preliminary assessment of the solar resource potential for West Africa and has generated the corresponding resource maps (ECREEE 2010).

In order to obtain the precise geographical coordinates of various locations in West Africa, I first downloaded the Google Earth software and selected two diagonally located cities or towns on a country's map so as to increase the chances of capturing significant climatic contrasts in a given country if they exist. The average insolation incident on a horizontal surface was then obtained by putting each coordinate into the NASA database on surface meteorology and solar energy, which is made available at no cost on the website of its Atmospheric Science Data Center. The latitude, longitude, elevation and corresponding insolation data (collected from January 1 2004 to December 31 2004) of the selected locations for analysis are displayed in Table 4.8 below.

Table 4.8 Solar Energy: Geographical Coordinates and Radiation Data (NASA 2012)

| | City | Latitude | Longitude | Elevation (m) | Solar Radiation (kWh/m2day) |
|---|---|---|---|---|---|
| Benin | Grand Popo | 6.28 | 1.84 | -0.31 | 4.84 |
| | Malanville | 11.87 | 3.38 | 220 | 5.61 |
| Burkina Faso | Niangoloko | 10.29 | 4.92 | 324 | 5.59 |
| | Falagountou | 14.36 | 0.18 | 261 | 6.29 |
| Cape Verde | Praia | 14.94 | 23.51 | -0.62 | 6.47 |
| | Mindelo | 16.87 | 24.98 | 58.2 | 6.74 |
| Côte d'Ivoire | San Pedro | 4.76 | 6.61 | 6.16 | 5.03 |
| | Bouaké | 7.69 | 5.04 | 323 | 4.78 |
| Gambia | Banjul | 13.46 | 16.58 | 4.62 | 6.01 |
| | Fatoto | 13.4 | 13.89 | 41.6 | 6.46 |
| Ghana | Axim | 4.87 | 2.24 | 1.23 | 5.25 |
| | Tamale | 9.41 | 0.85 | 168 | 5.23 |
| Guinea | Conakry | 9.53 | 13.69 | 16.6 | 5.76 |
| | Labé | 11.6 | 11.87 | -0.62 | 5.98 |
| Guinea Bissau | Bissau | 11.85 | 15.6 | 0 | 5.9 |
| | Bafata | 12.11 | 14.72 | 0 | 5.43 |
| Liberia | Monrovia | 6.34 | 10.78 | 13.9 | 5.09 |
| | Gbloyee | 6.34 | 10.78 | 283 | 5.21 |
| Mali | Kayes | 7.24 | 9.01 | 50.2 | 6.65 |
| | Abeïbara | 19.11 | 1.75 | 5.24 | 6.3 |
| Niger | Niamey | 13.5 | 2.1 | 247 | 6.13 |
| | Agadez | 16.97 | 7.99 | 509 | 6.56 |
| Nigeria | Lagos | 6.46 | 3.41 | 1.23 | 4.63 |
| | Maiduguri | 11.83 | 13.15 | 329 | 5.87 |
| Senegal | Ziguinchor | 12.58 | 16.28 | 9.86 | 5.94 |
| | Cascas | 16.38 | 14.07 | 8.01 | 6.79 |
| Sierra Leone | Freetown | 8.5 | 13.22 | 4.31 | 5.72 |
| | Kabala | 9.58 | 11.54 | 442 | 5.59 |
| Togo | Lomé | 6.14 | 1.21 | 18.2 | 4.84 |
| | Kara | 6.55 | 1.19 | 36.7 | 4.84 |

#### 4.2.3.1 Estimation of Electricity Potential from Solar Photovoltaics

The purpose of the calculations in this section is to demonstrate that solar energy can meet the unmet electricity needs of the region, and secondly, to determine how solar PV modules of different types could meet the minimum electricity requirements of a non-electrified household. Based on the technical potential of existing solar technologies, the solar resource in West Africa is shown to be sufficient to meet all its electricity needs. This type of broad assessment is frequently done to demonstrate the technical feasibility of using a given resource. For instance, in refuting the myth that the electricity demand in the U.S. can never be met by renewable energy, Sobin (2007) cites influential studies that show for instance that the amount of energy from sunlight that the U.S. receives is equivalent to 500 times its energy demands, and that about 0.4% of its area (or 10 million acres) could provide all the electricity consumed in the country using current PV technologies, even though this was not probable in practice in the near future. For the case of West Africa, I use existing data for average solar insolation at selected geographical coordinates to demonstrate this principle if 15% efficient solar cells were used. I then calculate how many PV modules would be needed to meet minimum household electricity requirements of 50 kWh, 100 kWh and 200 kWh in each country. The calculations used to estimate the electricity from solar energy that can theoretically be generated from land area available in each country in West Africa are shown below for the case of Burkina Faso.

The solar power that can be produced from a particular land area is given by

$$Power = Area * S_{avg} * \eta \quad \text{(Hafemeister 2007)}$$

where

$$S_{avg} = Average\ solar\ flux\ \left(\frac{kW}{m^2}\right) = Avg.solar\ radiation\left(\frac{kWh}{m^2 day}\right) * \left(\frac{1\ day}{24\ h}\right)$$

$$\eta = Efficiency\ of\ Solar\ PV\ cells$$

$$Area = Land\ area\ in\ a\ given\ country\ (m^2)$$

The solar energy produced in one year can then be calculated as:

$$Energy\ Generated = Solar\ Power * 8760\ hours = \left(Area * S_{avg} *\ \eta\right) * 8760\ hours$$

Thus, for Burkina Faso, for instance,

$$Energy\ Generated = [2.736 * 10^{11} m^2 * (5.94 \frac{kWh}{m^2 day} * \frac{1\ day}{24\ hrs}) *\ 0.15] * 8760\ hrs$$

$$= 3.16 * 10^{13} kWh = 3.16 * 10^7 GWh$$

This amount is about 45,930 times the total amount generated (688 GWh) in Burkina Faso in 2007 (see Table 4.1). Even though all of this energy is not practically usable through PV technology, the land area available, the average solar radiation in each country and the theoretical estimates are displayed in Appendix D1.

The calculations that follow below have then been used to estimate a practical policy, that is, the amount of solar energy that can be generated to meet the minimum monthly requirements of the Free Basic Electricity policy in South Africa that I use as a benchmark for providing access and some service to indigent households in West Africa, and which I simply call "Basic Electricity" (BE). I consider four sizes of either monocrystalline or polycrystalline PV modules (50 $W_p$, 80$W_p$, 130 $W_p$, 230 $W_p$)

available on the market that are suitable for use as Solar Home Systems (SHSs), and calculate how many of each type would be needed to meet the three possible minimum levels of electrification. Although this analysis has also been done by country, because West Africa is a tropical region and the variation in insolation levels is too small to make a significant difference, I present the region-wide results of the analysis, using the regional average for solar insolation for the purpose of demonstration. The results are shown in Table 4.9 below.

The approach to the estimation of the number of PV panels that would be needed to meet monthly basic electricity (BE) requirements of 50 kWh, 100 kWh and 200 kWh, is as follows:

The capacity factor (CF) of a solar PV panel, which is determined from the power rating on the panel at a peak solar flux of 1 kW/$m^2$ is given by:

$$CF_{PV} = S_{avg}/S_{peak} \qquad \text{(Hafemeister 2007)}$$

The solar energy generated by one panel is calculated as:

$$\begin{aligned} Energy\ Generated &= Average\ Solar\ Power * 30\ days * 24\ hours \\ &= Average\ Solar\ Power * 720\ hours \\ &= (Power\ rating * CF * Panel\ loss\ factor) * 720\ hours \end{aligned}$$

In this calculation, the panel loss factor includes a multiplier to account for operating temperature (0.9), a multiplier to account for losses through the cables (0.98), and the efficiency factor of an inverter (0.85), and an installation factor, which accounts for the incline, orientation and coatings on a PV panel (1.04) (Coley 2008).

Thus, for an average insolation of 5.718 kWh/m$^2$day in West Africa,

$$CF_{PV} = \frac{S_{avg}}{S_{peak}} = \frac{(5.718\,\frac{kWh}{m^2 day} * \frac{1\,day}{24\,hrs})}{1\,kW/m^2} = 0.238$$

The energy generated from one 50 $W_p$ (or 0.05 $kW_p$) is calculated as

$$Energy\ Generated = (Power\ rating * CF * Panel\ loss\ factor) * 720\ hours$$

$$= (0.05\ kW * 0.238 * 0.98 * 0.9 * 0.85 * 1.04) * 720\ hours$$

$$= 6.68\ kWh$$

Finally the number of 50 $W_p$ panels required to meet a BE of 50 kWh is:

$$No.of\ panels = \frac{Total\ energy\ generated}{Energy\ generated\ by\ one\ panel} = \frac{50\ kWh}{6.68\ \ kWh} = 7.5 = \sim 8\ panels$$

This calculation is extended to the other power ratings and for all the BE requirements and the results are shown in Table 4.9 below.

Table 4.9 Number of PV Modules Needed to Meet Monthly Basic Electricity Requirements

| | 50 kWh/mo | 100 kWh/mo | 200 kWh/mo |
|---|---|---|---|
| 50 $W_p$ panel | 8 | 16 | 32 |
| 80 $W_p$ panel | 5 | 10 | 20 |
| 130 $W_p$ panel | 3 | 6 | 12 |
| 235 $W_p$ panel | 2 | 4 | 7 |

In steps 1 to 11 in Table 4.10 below, I calculate the number of batteries that would be needed to store the energy required to meet each of the monthly electricity requirements. The total number of batteries is shown in step 11, which indicates that two, four and six batteries would be needed to meet monthly requirements of 50 kWh, 100 kWh and 200 kWh respectively.

Table 4.10 Number of Batteries Needed to Meet Basic Electricity Requirements

| | Measure* | 50 kWh/mo | 100 kWh/mo | 200 kWh/mo |
|---|---|---|---|---|
| 1 | Daily Amp-hr Requirement ($I*hr=P*hr/V_{system}$); $V_{system}$=12 V | 139 | 278 | 556 |
| 2 | # of days of autonomy (# of consecutive days of cloudy weather) | 2 | 2 | 2 |
| 3 | # of Amp-hrs battery needs to store (1 * 2) | 278 | 556 | 1111 |
| 4 | Depth of discharge | 0.5 | 0.5 | 0.5 |
| 5 | Effective Amp-hr requirement (3 ÷ 4) | 556 | 1111 | 2222 |
| 6 | Ambient temperature multiplier (at 80 F) | 1 | 1 | 1 |
| 7 | Total battery capacity needed (5 * 6) | 556 | 1111 | 2222 |
| 8 | Amp-hr rating of battery (6 V Surette 6CS25P) | 820 | 820 | 820 |
| 9 | # of batteries wired in parallel (7 ÷ 8) | 0.68 (~1) | 1.36 (~2) | 2.71 (~3) |
| 10 | # of batteries wired in series (Nominal V ÷ Battery V)=12V ÷ 6 V | 2 | 2 | 2 |
| **11** | **Total # of batteries required (9* 10)** | **2** | **4** | **6** |

Note: The specifications for the batteries are taken from the websites of manufacturers and vendors as well as the procedure for determining the number of required batteries.

### 4.2.4 Wind Energy

This section analyzes the potential of wind energy to meet the electricity access requirements of the region, and to contribute to reducing the unmet demand. Wind turbines convert the kinetic energy of the flowing wind into electricity. The wind speed varies by height, and for selected locations in West Africa, the geographical coordinates, their elevation and wind speeds at 10 m and at 50 m are shown in Table 4.11. A map of the wind resource across the entire continent of Africa is shown in Figure 4.2, though better resolution data in Table 4.11 shows that wind speeds in West Africa range from 2.21 m/s to 5.11 m/s at 10 m.

Table 4.11 Wind Energy: Geographical Coordinates and Wind Speeds (NASA 2012)

| | City | Latitude | Longitude | Elevation (m) | Wind speed at 10m (m/s) | Wind speed at 50m (m/s) |
|---|---|---|---|---|---|---|
| Benin | Grand Popo | 6.28 | 1.84 | -0.31 | 2.98 | 3.77 |
| | Malanville | 11.87 | 3.38 | 220 | 2.32 | 2.94 |
| Burkina Faso | Niangoloko | 10.29 | 4.92 | 324 | 2.31 | 2.92 |
| | Falagountou | 14.36 | 0.18 | 261 | 2.74 | 3.46 |
| Cape Verde | Praia | 14.94 | 23.51 | -0.62 | 4.21 | 5.33 |
| | Mindelo | 16.87 | 24.98 | 58.2 | 4.68 | 5.92 |
| Côte d'Ivoire | San Pedro | 4.76 | 6.61 | 6.16 | 2.95 | 3.45 |
| | Bouaké | 7.69 | 5.04 | 323 | 2.21 | 2.79 |
| Gambia | Banjul | 13.46 | 16.58 | 4.62 | 4.2 | 5.31 |
| | Fatoto | 13.4 | 13.89 | 41.6 | 4.15 | 5.25 |
| Ghana | Axim | 4.87 | 2.24 | 1.23 | 3.64 | 4.26 |
| | Tamale | 9.41 | 0.85 | 168 | 2.29 | 2.9 |
| Guinea | Conakry | 9.53 | 13.69 | 16.6 | 3.54 | 4.48 |
| | Labé | 11.6 | 11.87 | -0.62 | 3.58 | 4.53 |
| Guinea Bissau | Bissau | 11.85 | 15.6 | 0 | 4.04 | 5.12 |
| | Bafata | 12.11 | 14.72 | 0 | 5.11 | 4.04 |
| Liberia | Monrovia | 6.34 | 10.78 | 13.9 | 2.3 | 2.91 |
| | Gbloyee | 6.34 | 10.78 | 283 | 2.69 | 3.4 |
| Mali | Kayes | 7.24 | 9.01 | 50.2 | 4.37 | 5.53 |
| | Abeïbara | 19.11 | 1.75 | 5.24 | 4.42 | 5.6 |
| Niger | Niamey | 13.5 | 2.1 | 247 | 2.33 | 2.94 |
| | Agadez | 16.97 | 7.99 | 509 | 4.53 | 5.73 |
| Nigeria | Lagos | 6.46 | 3.41 | 1.23 | 3.64 | 4.26 |
| | Maiduguri | 11.83 | 13.15 | 329 | 3.79 | 4.8 |
| Senegal | Ziguinchor | 12.58 | 16.28 | 9.86 | 4.3 | 5.44 |
| | Cascas | 16.38 | 14.07 | 8.01 | 4.52 | 5.72 |
| Sierra Leone | Freetown | 8.5 | 13.22 | 4.31 | 3.37 | 4.26 |
| | Kabala | 9.58 | 11.54 | 442 | 3.4 | 4.3 |
| Togo | Lomé | 6.14 | 1.21 | 18.2 | 2.98 | 3.77 |
| | Kara | 6.55 | 1.19 | 36.7 | 2.98 | 3.77 |

4.2.4.1 Estimation of Electricity Potential from Wind Turbines

In estimating the potential to generate electricity from wind at a particular location, the primary factors that should be taken into consideration include site assessment, which consists of mapping the wind resource and choosing ideal locations for the turbines, optimal height of wind towers, and installation loads during the raising and lowering of the turbines (Wood 2011). The electrical power that can be generated by a wind turbine is given by

$$P_{wind} = 0.5\eta\rho v^3 A_{wind}$$ (Hafemeister 2007)

Where

$\eta$ = efficiency of the windmill = ~25%

$\rho$ = density of air = 1.293 kg/m$^3$

$v$ = average velocity of wind

$A_{wind}$ = Swept area of turbine with rotor diameter (d) = $\pi(d/2)^2$

The energy generated by such a wind turbine then, is given by

$$Energy_{wind} = P_{wind} * hours\ of\ operation$$

With respect to technology, we can observe from the equation for wind power above that other than the wind speed, the rotor diameter is the most important determinant of the power that can be produced by a wind turbine. Thus, even a given rated capacity on a turbine is only specified at a particular wind speed, which varies widely by place, but for that same rated capacity at the same location, a larger rotor diameter would cover a larger area, and hence produce more power. For small wind turbines, the typical rotor diameters that are typically used are 1.5m (micro) turbines used for fences or yatches, 2.5m (mid-range) normally used for single user remote or grid-connected households, and 5m (mini) used for mini grids or remote communities (Wood 2011).

Although the determination of wind potential is very model dependent, a rough estimate can be calculated by supposing the use of small wind turbines placed at an average height of 10 m over an area covering the land available in a given country. With respect to wind speeds, it should be noted that if they are too low, that is, below the *cut-in speed*, the turbine will not produce any power even though it may appear to be spinning. In his discussion of site assessment for small wind turbines, Wood (2011) states that as a rule of thumb, a wind speed of 5m/s can be considered a good value at an average height, but presents performance data for a small wind turbine that begins to produce power at a little over 2 m/s. He also demonstrates that for a small 2.4 kW Skystream turbine (diameter =3.72 m) at a height of 10.7 m, the dependence of average power on average wind speed is approximately linear (in contrast with the cubic relationship between instantaneous power and instantaneous speed), especially for wind speeds of less than 8 m/s. Furthermore, if the use of high tech controllers is assumed, the small amounts of energy available in the alternator windings at low wind speeds can be pulsed to the batteries to be stored. Since all the ECOWAS countries have average wind speeds that are at least 2.2 m/s or more at a hub height of 10 m, the assumption that the corresponding power calculated can be generated is justifiable for the purpose of this analysis. If we consider the country of Cape Verde for instance, with a land area of 4,030 $km^2$ or $4.03 * 10^9$ $m^2$, then the wind volume is:

$$V_{wind} = A_{wind} * height = 4.03 * 10^9 m^2 * 10m = 4.03 * 10^{10} m^3$$

Also, assuming the use of windmills operating at 25% efficiency (the theoretical maximum or Betz limit is 59%), the wind power that can be produced in Cape Verde, with an average wind velocity of 4.44 m/s is:

$$P_{wind} = 0.5\eta\rho v^3 V_{wind} = 0.5 * 0.25 * \frac{1.293kg}{m^3} * \left(\frac{4.44m}{s}\right)^3 * 4.03 * 10^{10} m^3$$

$$= 5.701 * 10^{11} W_e = 570.1\ GW$$

The on-shore wind energy potential from Cape Verde in one year at 10 m can then be calculated as:

$$Energy_{wind} = P_{wind} * hours\ of\ operation = 570.1\ GW * 8760\ hours$$

$$= 5.0 * 10^6 GWh$$

At 50 m, where the wind speed is 5.62 m/s, the wind energy potential from Cape Verde would be equal to $5.1 * 10^7$ GWh, thus an order of magnitude higher.

At 10 m, the wind energy potential is about 19,230 times the met demand of 260 GWh in Cape Verde, while at 50 m, it is about 194,900 times the demand. As with the solar energy resource in the previous section, the analysis above shows that there is also a sufficient wind energy resource to meet the electricity needs of the region in principle. The calculation is replicated for all other ECOWAS countries and the results are presented in Appendix D2.

To demonstrate the consumption of this energy resource in practice, I once again use the three "Basic Electricity" (BE) scenarios of 50kWh/month, 100 kWh/month and 200 kWh/month as in the previous section, and estimate how the small wind turbine rotor dimensions of 1.5 m, 2.5 m, and 5 m could meet this demand. For a wind turbine with a rotor diameter of 2.5 m, for example, the electricity produced in Cape Verde with an average annual wind speed of 4.44 m/s is:

$$P_{wind} = 0.5\eta\rho v^3 A_{wind} = 0.5\eta\rho v^3 \pi (\frac{d}{2})^2$$

$$= 0.5 * .25 * \frac{1.293kg}{m^3} * \left(\frac{4.44m}{s}\right)^3 * \pi \left(\frac{2.5m}{2}\right)^2 = 69.51\ W_e$$

The energy that can be generated in one month is then calculated as

$$Energy_{wind} = P_{wind} * hours\ of\ operation = 69.45\ We * 30\ days * 24\ hours$$

$$= 50004\ Wh = 50.004\ kWh$$

Thus, the number of turbines needed to meet a BE of 50 kWh per month is

$$No. of\ turbines = \frac{Total\ energy\ generated}{Energy\ generated\ by\ one\ turbine} = \frac{50\ kWh}{50.004\ \ kWh} = 0.999$$

$$= \sim 1\ turbine$$

This calculation is extended to the other rotor diameters and for all the BE requirements for West Africa as a whole and the results are shown in Table 4.12 below. The number of batteries needed to meet the BE requirements is approximately the same as that shown in Table 4.10. Thus, two, four and six batteries are needed in combination with the turbines to produce BE requirements of 50 kWh, 100 kWh and 200 kWh respectively.

Table 4.12 Number of Wind Turbines per Household Needed to Produce Minimum Electricity Requirements

| | BE = 50 kWh/mo | BE = 100 kWh/mo | BE = 200 kWh/mo |
|---|---|---|---|
| 1.5 m turbine | 6 | 12 | 23 |
| 2.5 m turbine | 2 | 4 | 8 |
| 5 m turbine | 0.5 (~ 1) | 1 | 2 |

The preceding analyses have demonstrated some of the ways in which solar and wind energy can increase energy access and meet minimum basic electricity requirements in West Africa as defined in this chapter. I estimate the percentage of the total demand shortfall that can be met if the minimum monthly basic electricity requirements per household are fulfilled either through solar energy, wind energy, biomass energy, or any combination thereof. The approach consists of multiplying the percentage of people without electricity access by the total population to determine the number of people without access. Based on the assumption that the average household is made up of five individuals (culled from various national government websites), the number of households without access can then be calculated by dividing the total population by five. The total electricity that needs to be generated in order to meet the basic monthly electricity requirements of 50 kWh, 100kWh and 200kWh is shown in Table 4.13, and the percentage of the total demand shortfall that this represents is shown in Table 4.14.

Table 4.13 Estimated Electricity Generated (GWh) to meet Basic Electricity Requirements.

| | Total Population (UNDP-HDI page) | Fraction Without Electricity Access | BE=50 kWh/mo (GWh/yr) | BE=100 kWh/mo (GWh/yr) | BE=200 kWh/mo (GWh/yr) | Total Demand Shortfall (GWh/yr) |
|---|---|---|---|---|---|---|
| Benin | 9,099,900 | 0.75 | 819 | 1638 | 3276 | 2041 |
| Burkina Faso | 16,967,800 | 0.9 | 1833 | 3665 | 7330 | 6376 |
| Cape Verde | 500,600 | 0.3 | 18 | 36 | 72 | 175 |
| Côte d'Ivoire | 20,152,900 | 0.53 | 1282 | 2563 | 5127 | 4111 |
| Gambia | 1,776,100 | 0.92 | 196 | 392 | 784 | 2156 |
| Ghana | 24,965,800 | 0.46 | 1378 | 2756 | 5512 | 8513 |
| Guinea | 10,221,800 | 0.8 | 981 | 1962 | 3925 | 3583 |
| Guinea Bissau | 1,547,100 | 0.89 | 165 | 331 | 661 | 208 |
| Liberia | 4,128,600 | 0.97 | 481 | 961 | 1922 | 641 |
| Mali | 15,839,500 | 0.83 | 1577 | 3155 | 6311 | 4215 |
| Niger | 1,606,900 | 0.91 | 176 | 351 | 702 | 7579 |
| Nigeria | 162,470,700 | 0.53 | 10333 | 20666 | 41333 | 86366 |
| Senegal | 12,767,600 | 0.58 | 889 | 1777 | 3555 | 2666 |
| Sierra Leone | 5,997,500 | 0.95 | 684 | 1367 | 2735 | 1418 |
| Togo | 6,154,800 | 0.8 | 591 | 1182 | 2363 | 2792 |
| Total | 294197600 | | 21402 | 42804 | 85608 | 132840 |

Table 4.14 Percentage of Total Demand Shortfall Met through Basic Electricity Requirements

| | % total demand shortfall (50kWh/mo) | % total demand shortfall (100kWh/mo) | % total demand shortfall (200kWh/mo) |
|---|---|---|---|
| Benin | 40% | 80% | 160% |
| Burkina Faso | 29% | 57% | 115% |
| Cape Verde | 10% | 21% | 41% |
| Côte d'Ivoire | 31% | 62% | 125% |
| Gambia | 9% | 18% | 36% |
| Ghana | 16% | 32% | 65% |
| Guinea | 27% | 55% | 110% |
| Guinea Bissau | 80% | 159% | 319% |
| Liberia | 75% | 150% | 300% |
| Mali | 37% | 75% | 150% |
| Niger | 2% | 5% | 9% |
| Nigeria | 12% | 24% | 48% |
| Senegal | 33% | 67% | 133% |
| Sierra Leone | 48% | 96% | 193% |
| Togo | 21% | 42% | 85% |
| Total | 16% | 32% | 64% |

The analysis of the percentage of the total demand shortfall that can be attained by fulfilling minimum electricity requirements for non-electrified households suggests that all but two countries, being the Gambia and Niger, could meet at least 10% of their demand shortfall by implementing a 50 kWh/month minimum requirement, while only Niger would not be able to meet at least 10% of its total demand shortfall by implementing a 100 kWh/month minimum requirement and only Niger would still be unable meet at least 10% of its total demand shortfall by implementing a 200 kWh/month minimum requirement. On the other hand, two countries, Guinea Bissau and Liberia, could meet over 100% of their total demand shortfall if each household consumed 100 kWh/month of electricity, and nine out of fifteen countries could meet over 100% of their demand shortfall if each household consumed 200 kWh/month of electricity.

Of the six countries that did not satisfy up to 100% of their total demand shortfall through BE requirements of 200 kWh/month, it can be observed that Cape Verde, Ghana and Nigeria have relatively high electrification rates and therefore, the demand shortfall may be more related to commercial or industrial requirements and the "unmet" demand for those connected to the grid, particularly in the case of Nigeria. On the other hand, the three other countries, namely, the Gambia, Niger, and Togo, have low electrification rates, but the specific reason for the relatively low potential contribution of household energy consumption to reducing the total demand shortfall, particularly in the case of Niger, is unclear. This may be related to specific national policies or requirements that are difficult to unpack through the numbers alone.

### 4.3 Cost Analysis: HOMER Modeling

The purpose of this section is to identify the most cost-effective technology options for off-grid distributed electrification in West Africa when compared to diesel generators, as well as highlight which ones are environmentally preferable with respect to their level of emission of pollutants, although no costs are assessed to the latter.

However, a particularly productive approach that been has been described in a number of studies involves the use of spatial modeling based on a network expansion algorithm to model the comparative costs of centralized and decentralized electrification. Deichmann, Meisner et al. (2011), for instance, apply this approach to Sub-Saharan Africa, and use their findings to argue that decentralized renewable energy, though becoming increasingly more important, will be the least cost option for only a minority of African households over the next 20 years. The authors appear to have arrived at this conclusion in part because they did not seriously consider any of the institutional or technological capability factors that might affect the results of their economic analysis. More specifically, they obtained their results because their assumptions about the capital costs of solar PV panels, for example, and their discount rates are much higher than those used in other peer reviewed studies that obtained their data from field studies, and that were used in this chapter.

Another study by Levin and Thomas (2011) also uses a network algorithm to determine the conditions under which centralized or decentralized electrification can be provided at least-cost across the globe, but they demonstrate that for most of the world's population, especially in Africa, large regions can be served by decentralized electrification at low cost. Levin and Thomas (2011) further point out that irrespective of the results of their economic analysis, the advantages of decentralized electricity with respect to the installation time (days as opposed to years for centralized generation), accessibility and reliability, could make it attractive even in countries that have high population densities such as in Bangladesh. These additional factors would likewise be critical in the West African situation in light of the stakeholder analysis and policy evaluation in Chapter Three of this dissertation.

The main tool I use for the analysis of the costs of the distributed renewable energy options described in this chapter is the Hybrid Optimization Model for Electric Renewables (HOMER), which has been developed by the U.S. National Renewable Energy Laboratory (NREL). HOMER is a micropower optimization model that simplifies the evaluation of both off-grid and grid-connected power system designs for different applications (NREL 2005). It works by performing three main tasks, namely, simulation, optimization and sensitivity analyses.

The software first simulates the operation of a given system configuration by making energy balance calculations for each of the 8,760 hours in the year, and then determines whether the configuration is possible. It does this by verifying whether it can meet the electric demand under specified conditions and by estimating the installation and operating costs over the lifetime of the project, which include capital costs, replacement costs, operation and maintenance costs, fuel, and interest. HOMER optimizes the system by simulating all its possible configurations and displays them as a list of the lowest to the highest net present cost, which it also defined as the life cycle cost, in order to compare different design alternatives. The software also performs a sensitivity analysis by repeating the optimization process for each sensitivity variable that is specified, such as a range of wind speeds, or a range of diesel prices.

The cost analysis in this section evaluates five scenarios as follows: 1.) diesel-only; 2.) biomass power versus diesel; 3.) solar power versus diesel; 4.) wind power versus diesel, and 5.) hybrid solar-wind power versus diesel. The main components of the analyses that I present below include a description of all the technology and cost assumptions that I make, a display of the net present cost (life cycle cost) of the optimized technology options, the levelized cost of electricity for each energy resource, and a display of the emissions released by each of the resource options. I assume that the analyses presented are generalizable for the region in terms of purchasing power parity (PPP) because nine of the fifteen ECOWAS countries share the same Central Bank and currency, the CFA Franc, which also heavily influences the activities of the other countries, with the possible exception of Ghana and Nigeria.

The inputs for the economic analysis are based in part on the assessment of the technology and resource options for solar, wind and biomass that could satisfy the unmet electricity demand, and that have been presented in the previous sections. I rely on two publications on decentralized electricity policy in Senegal (which is in the CFA Franc zone) for the local costs of the small scale technologies as these were obtained through interviews and surveys with reputable national and regional organizations based in the country (Thiam 2010; Thiam 2011). I also draw on the work of Dasappa (2011) on biomass electricity generation in sub-Saharan Africa for cost data. The table below shows the technologies and costs that were used for the HOMER analyses.

Table 4.15 Technical Specifications and Costs of Selected Components of Energy Systems

| | Capacity | Capital Costs | Operating Costs | Fuel Costs | Lifetime |
|---|---|---|---|---|---|
| Biomass generator | 10 kW | $900/kW= $9000 | $19/yr=$0.002/hr | $50/ton | 15,000 hrs |
| Solar PV | 235 W | $3700/kW =$869.5 | $3/yr=$0.0003/hr | $0 | 20 yrs |
| Wind turbine | 1.8 kW | $2500/kW =$4500 | $4/yr=$0.0005/hr | $0 | 15 years |
| Diesel Generator | 450 W | $370 | $19/yr=$0.002/hr | $1.34/L | 15,000 hrs |
| Biomass gasifier | 10 kW | $300/kW= $3000 | $0.035/hr | N/A | 15,000 hrs |
| Battery | 6 V | $700 | N//A | N/A | 12 yrs |
| Charge Controller | 6 Amp, 12 V | $50 | N/A | N/A | |

### *4.3.1 Simulation*

The schematics of the five simulation exercises as they were conducted in HOMER are shown in Figures 4.3 to 4.7 below, where Generator 1 represents the diesel generator, and the primary load represents a basic electricity load of 200 kWh/month (or

6.7 kWh/d). The icon with "S6CS25P" label in Figures 4.5 to 4.7 represents a Surrette battery with a nominal voltage of 6 V that was selected from several battery options in HOMER because its specifications are consistent with the assumptions that were made in calculating the number of batteries that would be needed for each monthly BE requirement (See Table 4.10). The icons under "Resources" allow the modeler to import characteristics such as average daily wind speed for every month of the year, the average daily solar radiation per month, modify the average daily amount of biomass used per month (tonnes/day) and the average price of the biomass used ($/tonne), and enter the average fuel price ($/L) in the case of diesel.

For the icons under "Other", the user can modify parameters such as the annual real interest rate (which I changed from 6% to 7% in West Africa), the project lifetime, and or the system capital and O&M costs. The systems control inputs determine how HOMER controls the way that the system charges the battery bank (I did not modify this), the "emissions" function allows the user to put a cap on emissions (kg/yr) and to impose costs on emissions ($/tonne), but I did not impose either of these. A converter icon is also shown in Figures 4.10 to 4.12 because the diesel generator runs on electricity in an Alternating Current (AC) form, while the wind and solar generators run on a Direct Current (DC), which requires a converter in the form of an inverter (to convert DC to AC) or what is generically called a "converter" to convert AC to DC. However, if household devices use a type of current that is the same as that of the generator being used, a converter is not needed.

The constraints function allows the user to impose a minimum renewable fraction or modify parameters like the electrical efficiency or thermal efficiency of the devices, but I used the standard values for typical devices that were established in the software package. Lastly, the number of times that the software ran the simulation per exercise (based on the inputs) is in brackets under the title of each schematic.

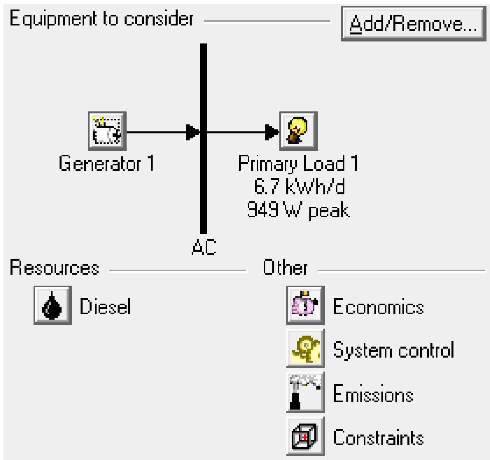


Fig. 4.1 Diesel Power Only (6x)

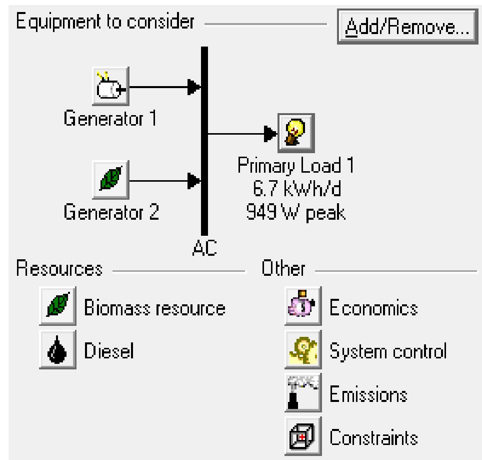


Fig. 4.2 Biomass Power versus Diesel (36x)

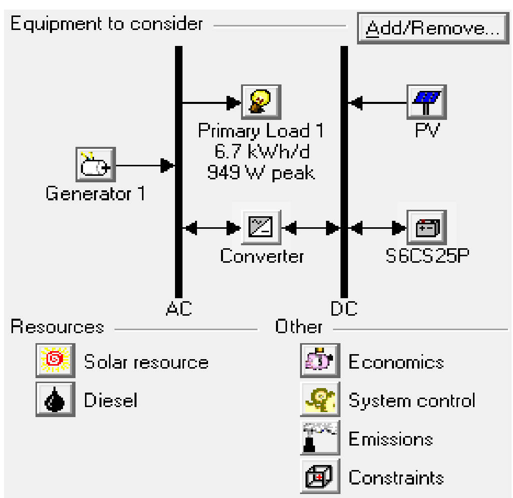


Fig. 4.3 Solar Power versus Diesel (144x)

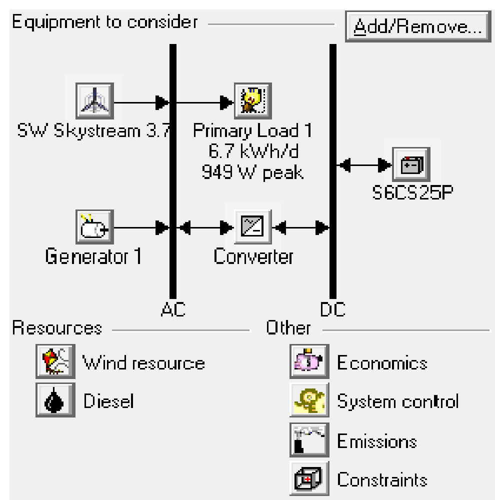


Fig. 4.4 Wind Power versus Diesel (96x)

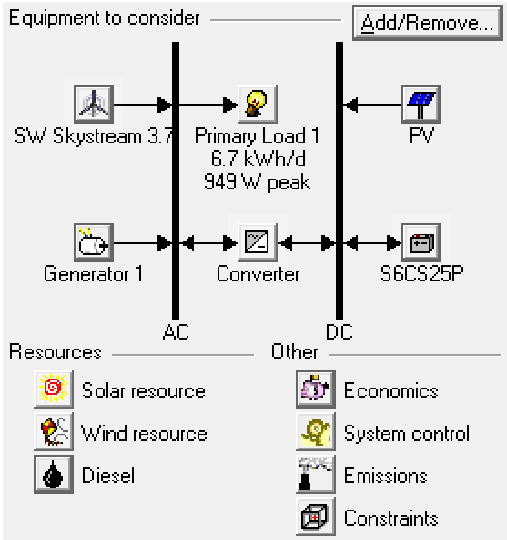


Fig. 4.5 Solar-Wind Hybrid versus Diesel (840x)

### *4.3.2 Optimization*

The optimization procedure that HOMER performs, which consists of simulating all the possible configurations of a system and ranking the most optimal configuration from the least expensive one to the most expensive, does not provide the "solution" to the problem per se, but only allows the user to compare various alternative designs. Even though optimization itself, understood as the result of a formal objective function, runs counter to the logic of continuous learning in AM, it does help to clarify given objectives under specific conditions such that learning can then occur over multiple iterations (Walters 1986). Thus, the results presented in this section are intended to show the costs associated with the various alternatives even though the least cost one is not necessarily the preferred alternative in practice.

For instance, a user in an off-grid location might not be able to afford the capital cost of two or three different generators at one time even though a particular combination may provide the cheapest levelized cost of electricity (LCOE) over their life cycle according to the model. The results of the optimization for the 50 kWh/month basic electricity requirement are shown in Figures 4.8 to 4.12 below for all five scenarios. In the first figure for the diesel-only scenario, the labels in order are as follows: The Label (kW) tab represents the installed capacity of the diesel or biomass generator in Figures 4.8 and 4.9, followed by the initial capital required to install it, the operating costs per year, the total Net Present Cost (NPC) or life cycle cost, the levelized cost of electricity (COE), the fraction of renewable energy in the resource used, the volume of diesel used, and finally Label (hrs) represents the total number of hours of operation of the generator. Subsequent figures also show the components of the PV and wind turbine systems, and display the costs of all the feasible configurations.

I should note here that the data that HOMER uses for the solar resource is the Global Horizontal Radiation (GHR), which is slightly lower than the average daily solar insolation on a horizontal surface that I obtained from the NASA data, because the GHR contains a clearness index. Unfortunately, HOMER gets this data from a combination of different sources which are difficult to track, but there is a strong correlation between the GHR and the average solar insolation. However, I was required to input all the wind data into HOMER manually as the software does not generate this data directly. In addition, the coordinates that were used to generate the results below are from the city of Conakry, Guinea, which I selected because both its average solar insolation and average wind speed are very close to the regional averages.

Figures 4.6 to 4.10 below show the optimization results for the five scenarios that were simulated. The most optimal configuration, shown in the first line, is the one with the lowest total net present cost (NPC) as well as the lowest levelized cost of electricity (COE). Each additional line then represents a gradual increase in cost with the most expensive configuration being in the last line. The tab labeled “Label (kW)” represents the optimal number of diesel or biomass generators, while those labeled “PV (kW)” and “”S3.7” represent the solar and wind generators respectively that would be needed to supply the required load of 50 kWh/month (or 1.67 kW/day in the input format required by the model).

The numbers or figures under the different tabs signify the following. In the first line of Figure 4.6, for instance, 0.45 kW under Label (kW) represents one 450 W diesel generator. In the first line of Figure 4.7, the generator under first tab represents a diesel generator, while the leaf under the second generator tab represents a biomass generator. The next two tabs then represent the optimal number of generators needed to meet the 50 kWh/month load. Thus, 0.90 kW in the first Label (kW) tab represents two 450 W generators for a total of 900 W, while the second tab represents a 10 kW biomass generator. In the second line of Figure 4.7, which represents the second most optimal configuration for that load, we have 1.8 kW which indicates that four 450 W diesel generators (1800 W) were used, but no biomass generator. Similarly, in the first line of Figure 4.8, the PV (kW) tab showing 0.470 kW means two 235 W Solar panels for a total installed capacity of 470 W. The next tab is the 450 W generator, followed by the S6CS25P and Conv (kW) tabs, which respectively show that 10 batteries and one converter are needed for the configuration in that line to satisfy a load of 50 kWh/month.

It should be noted here that I put in the maximum number of batteries as 10 (based on the calculation shown in Table 4.10) and one converter to run those particular simulations, but these numbers can easily be changed in order to increase or decrease the "search space" or range of values that the model uses for its optimization procedure. Lastly, in Figures 4.9 and 4.10, the S3.7 tab represents the number of wind turbines that are required for a given configuration to meet a demand of 50 kWh/month.

Fig. 4.6 Diesel Power Only (50kWh/month)

| Label (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Label (hrs) |
|---|---|---|---|---|---|---|---|
| 0.45 | $ 370 | 1,044 | $ 12,534 | 1.764 | 0.00 | 613 | 8,759 |

Fig. 4.7 Biomass Power versus Diesel (50kWh/month)

| Label (kW) | Label (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Biomass (t) | Label (hrs) | Label (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.90 | 10 | $ 12,740 | 3,253 | $ 50,645 | 0.893 | 0.53 | 1,429 | 7 | 7,424 | 1,335 |
| 1.80 | | $ 1,480 | 4,492 | $ 53,823 | 0.949 | 0.00 | 2,688 | | 8,759 | |

Fig. 4.8 Solar Power versus Diesel (50kWh/month)

| PV (kW) | Label (kW) | S6CS25P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Label (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.470 | 0.45 | 10 | 1 | $ 2,860 | 83 | $ 3,827 | 0.539 | 0.90 | 25 | 167 |
| 0.940 | | 10 | 1 | $ 4,230 | 78 | $ 5,134 | 0.723 | 1.00 | | |
| | 0.45 | 10 | 1 | $ 1,120 | 450 | $ 6,360 | 0.895 | 0.00 | 287 | 1,931 |
| 0.470 | 0.45 | | 1 | $ 2,160 | 811 | $ 11,612 | 1.635 | 0.43 | 464 | 6,639 |
| | 0.45 | | | $ 370 | 1,044 | $ 12,534 | 1.764 | 0.00 | 613 | 8,759 |

Fig. 4.9 Wind Power versus Diesel (50kWh/month)

| S3.7 | Label (kW) | S6CS25P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Label (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.45 | 10 | 1 | $ 1,120 | 450 | $ 6,360 | 0.895 | 0.00 | 287 | 1,931 |
| 1 | | 10 | 1 | $ 5,250 | 150 | $ 6,997 | 0.985 | 1.00 | | |
| 1 | 0.45 | 10 | 1 | $ 5,620 | 144 | $ 7,300 | 1.028 | 1.00 | | 0 |
| | 0.45 | | | $ 370 | 1,044 | $ 12,534 | 1.764 | 0.00 | 613 | 8,759 |
| 1 | 0.45 | | | $ 4,870 | 793 | $ 14,110 | 1.986 | 0.67 | 398 | 5,703 |

Fig. 4.10 Solar-Wind Hybrid Power versus Diesel (50kWh/month)

| PV (kW) | S3.7 | Label (kW) | S6CS25P | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Label (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.470 | | 0.45 | 10 | 1 | $ 2,860 | 108 | $ 4,121 | 0.580 | 0.90 | 25 | 167 |
| 0.940 | | | 10 | 1 | $ 4,230 | 78 | $ 5,134 | 0.723 | 1.00 | | |
| | 1 | 0.45 | 10 | 1 | $ 5,620 | 171 | $ 7,611 | 1.071 | 0.98 | 11 | 74 |
| 0.470 | 1 | | 10 | 1 | $ 6,990 | 174 | $ 9,016 | 1.269 | 1.00 | | |
| 0.470 | 1 | 0.45 | 10 | 1 | $ 7,360 | 168 | $ 9,320 | 1.312 | 1.00 | | 0 |
| | | 0.45 | 10 | 1 | $ 1,120 | 741 | $ 9,758 | 1.374 | 0.00 | 287 | 1,931 |
| | 2 | | 10 | 1 | $ 9,750 | 270 | $ 12,898 | 1.816 | 1.00 | | |
| 0.470 | 1 | 0.45 | | 1 | $ 6,660 | 1,320 | $ 22,047 | 3.104 | 0.78 | 306 | 4,385 |
| 0.940 | | 0.45 | | 1 | $ 3,900 | 1,603 | $ 22,580 | 3.179 | 0.63 | 404 | 5,777 |
| | 1 | 0.45 | | | $ 4,870 | 1,676 | $ 24,396 | 3.434 | 0.66 | 404 | 5,782 |
| | | 0.45 | | | $ 370 | 2,366 | $ 27,947 | 3.934 | 0.00 | 613 | 8,759 |

### *4.3.3 Sensitivity Analysis*

The sensitivity analysis feature in HOMER most closely models the concept of component sizing, which has been used in this chapter to capture the possibility of gradually and adaptively building up electricity generation infrastructure. What the model does here is that it runs the optimization procedure described in the previous section for a BE of 50 kWh/ month for each of the BE requirements from 50 kWh to 800 kWh per month. This step is consistent with Principle #2 of the eight principles of a regional risk planning model in the face of uncertainty outlined by Kai Lee, which requires a range of minimum electricity requirements to be modeled for different energy sources, rather than simply using a specific or an intermediate forecast. The search space feature also allowed me to input a range of capacities of 0 to 100 kW for the diesel, PV and biomass generators, 0 to 100 turbines for the wind generator, and a range for the number of batteries from 0 to 200, which I thought would be sufficient to generate the different BE requirements.

However, the main purpose of the sensitivity analysis was to determine what combination of the components could produce the daily equivalent of the monthly primary loads of 50 kWh, 100 kWh, 200 kWh, 400 kWh and 800 kWh, and to subsequently observe the evolution of the levelized cost of electricity (LCOE) with an increase in consumption. I changed the discount rate in HOMER from 6% to 7% because the range of rates culled from the literature range from 4.5% for solar and wind (Thiam 2011) to 10% for biomass gasification, diesel and dual fuel generators (Dasappa 2011), and so 7% was used because it can be considered to be a representative value that cuts across all the technologies. Table 4.16 below shows the levelized costs for the five scenarios and the corresponding optimal fraction of renewable energy in brackets below each cost. Figure 4.11 below then shows the levelized cost curves for the various scenarios that were produced from the sensitivity analysis.

Table 4.16 Levelized Cost of Electricity (LCOE) across Five Hybrid Scenarios

| Primary Load (kWh) | Diesel ($/kWh) | Biomass-diesel ($/kWh) | Solar-diesel (S/kWh) | Wind-diesel ($/kWh) | Solar-wind-diesel ($/kWh) |
|---|---|---|---|---|---|
| 50 | 1.76 (0.00) | 1.76 (0.00) | 0.54 (0.90) | 0.90 (0.00) | 0.58 (0.90) |
| 100 | 0.95 (0.00) | 0.95 (0.00) | 0.45 (0.88) | 0.63 (0.84) | 0.51 (0.88) |
| 200 | 0.95 (0.00) | 0.95 (0.00) | 0.42 (0.80) | 0.59 (0.49) | 0.45 (0.96) |
| 400 | 0.95 (0.00) | 0.89 (0.53) | 0.47 (0.58) | 0.56 (0.50) | 0.51 (0.82) |
| 800 | 2.45 (0.00) | 0.69 (0.36) | 0.50 (0.89) | 0.56 (0.27) | 0.48 (1.00) |

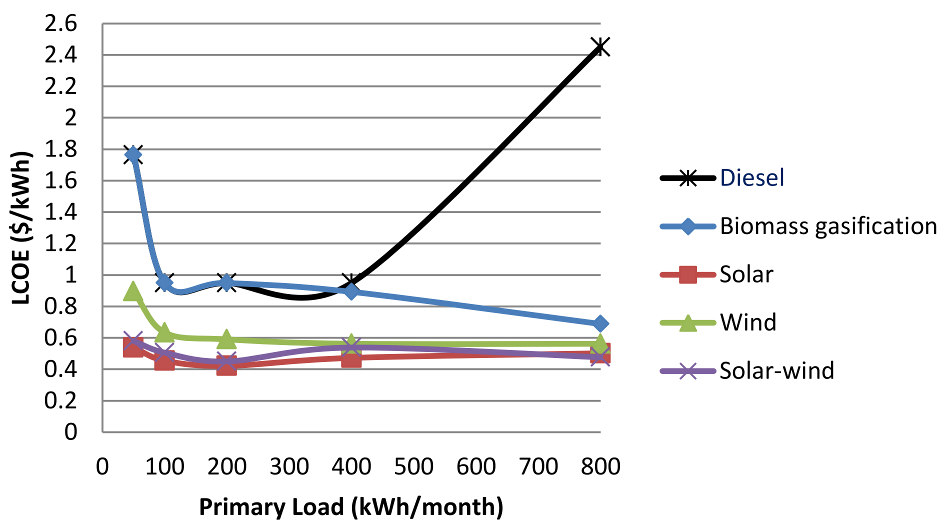


Figure 4.11 Evolution of Levelized Costs of Electricity (LCOE) across Five Hybrid Scenarios

Figure 4.11 above shows that the solar-diesel scenario has the lowest LCOE across the board, as consumption increases from 50 kWh to 800 kWh, followed by the hybrid solar-wind-diesel up to 400 kWh, then wind-diesel across the board, with biomass-diesel and finally diesel-only rounding out the most expensive resources. It can also be noted that while for the biomass-diesel, solar-diesel, wind-diesel and solar-wind-diesel hybrid scenarios, LCOE decreases rapidly from 50 kWh to 100 kWh, the initial cost at 50 kWh being high due to the higher proportion of the capital cost, and then stabilizes with increased consumption, or continues to drop in the case of biomass. The cost of the diesel-only scenario increases exponentially from 400 kWh to 800 kWh because of the LCOE value of diesel is high at first as a result of the higher proportion of the capital cost of the generator at the lowest level of consumption, but stabilizes as electricity is consumed, only to increase again with an increase in energy consumption, which can be mainly attributed to the increased use of the diesel fuel, as well as additional generators required to meet the new demand. On the other hand, only the capital cost impacts renewable energy technologies as there is no cost for their fuels.

Furthermore, in the biomass gasification system, biomass does not become cost effective until consumption reaches close to 400 kWh, since its renewable energy fraction is 0.0 up to 200 kWh, and the diesel and biomass-diesel cost curves are nearly identical until about 300 kWh. Lastly, in the case, of the solar-wind-diesel scenario, at a consumption level of 800 kWh, the renewable energy fraction becomes 1.00, and there is no need for diesel. Across all scenarios, the highest LCOE values are associated with the diesel-only scenario with $1.76/ kWh at 200 kWh/month and $2.45/kWh at 800 kWh/month. On the other hand, the lowest LCOE values are $0.42/kWh for the solar-diesel scenario at 200kWh/month with an 80% proportion of renewable energy, and at 800 kWh/month, it is $0.48/kWh in the solar-wind-diesel scenario.

Another interesting finding is that even though the renewable energy fraction of the wind energy system is 0.0 at a load of 50 kWh, the LCOE for the wind-diesel scenario is still much lower than that of the diesel-only scenario. This can be explained by the fact that in the first line of the simulation diagram for the wind-diesel scenario in Figure 4.9, which is the most optimal configuration, there is a diesel generator, a battery, and a converter, while in the diesel-only scenario, there is no battery at all. Therefore, even though the electricity from the wind turbine is not yet cost-effective at 50 kWh, the battery stores the energy produced by the diesel generator, and the use of some of this battery power rather than only the diesel fuel makes the wind system cheaper than that of diesel. A closer look at the data output from HOMER as seen in Figures 4.6 to 4.10 reveals a few instances of this dynamic, but it is also known that in rural areas, residents will sometimes take their batteries to be charged by others who own diesel generators for a small fee, in order to run their TVs or other small appliances.

It should be noted, however, that in practice, most households that are not connected to the grid in West Africa are not likely to be able to afford to purchase two or three generators in order to find the most cost-effective combination of these that will meet their electricity requirements. This would be particularly true in the initial stages of electrification, but as more households in these areas adopt various technologies, it would become possible for clusters of households to share their different sources of energy in a type of community arrangement. Thus, the hybrid modeling exercise described above helps to provide insights into the different levels of consumption at which various energy technologies can become cost effective, and can serve as the basis for future hybrid energy resource planning through microgrids. Table 4.17 and Figure 4.12 below then show LCOE values across five stand-alone scenarios of diesel, biomass, solar, wind, and a solar-wind scenario, that would be closer to the current reality in West African countries.

Table 4.17 Levelized Cost of Electricity (LCOE) across Five Stand-alone Scenarios

| Primary Load (kWh) | Diesel ($/kWh) | Biomass-only ($/kWh) | Solar-only ($/kWh) | Wind-only ($/kWh) | Solar-wind-only ($/kWh) |
|---|---|---|---|---|---|
| 50 | 1.76 | 17.02 | 0.54 | 0.985 | 0.73 |
| 100 | 0.95 | 8.54 | 0.63 | 1.15 | 0.58 |
| 200 | 0.95 | 4.26 | 0.42 | 1.41 | 0.61 |
| 400 | 0.95 | 2.14 | 0.91 | 1.24 | 0.76 |
| 800 | 2.45 | 1.08 | 0.54 | 1.44 | 0.48 |

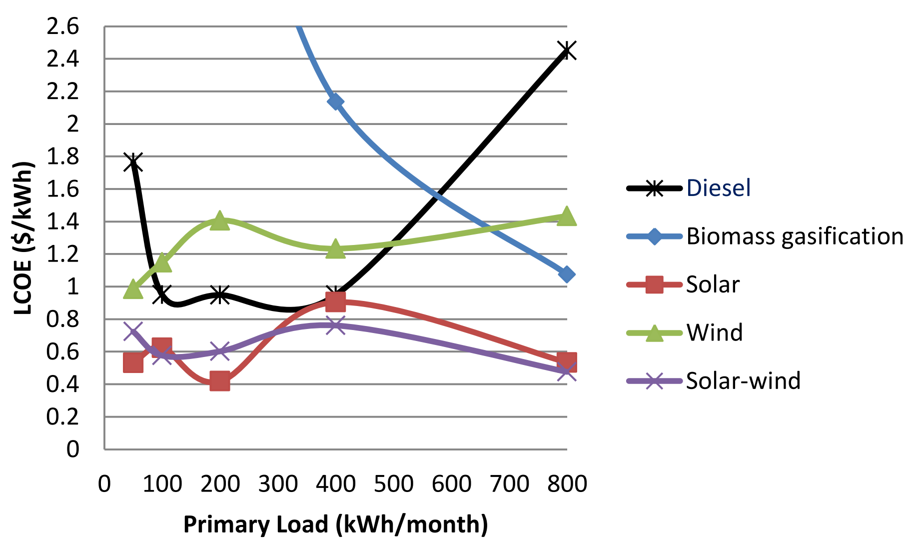


Figure 4.12 Evolution of Levelized Costs of Electricity (LCOE) across Five Stand-alone Scenarios

In Table 4.18 above, it can be observed that the diesel-only case is the same as in the hybrid scenarios shown in Table 4.17, with the initial LCOE value at 50 kWh/month decreasing at 100 kWh/month and stabilizing until 400 kWh/month after which, it increases exponentially to 800 kWh/month. However, the biomass-only scenario starts at a very high LCOE value of $17.02/kWh at 50 kWh/month and decreases rapidly to $1.08/kWh at 800 kWh/month. Of the three renewable energy scenarios, the cost of wind is the most stable across the board, while the cost of the solar-only and solar-wind scenarios are comparable, with both having the lowest LCOE values of $0.54/kWh and $0.48/kWh respectively across all scenarios at 800 kWh/month.

## 4.4 Emissions

HOMER automatically calculates the amount of the various emissions that are released from the use of various resources as part of the optimization procedure. Table 4.18 below shows the emissions result for all five hybrid scenarios for a household that consumes 200 kWh/month, and a similar result can also be retrieved for the other loads. It should be noted that these results represent emissions that are proportional to the fractions of renewable versus diesel in all the hybrid scenarios that were run as shown in the optimization results in Figures 4.8 to 4.12. The diesel generator emits the largest amount of $CO_2$ as well as all the other pollutants. Biomass only becomes cost-effective around 400 kWh so I have scaled the emissions down in order to get the equivalent emissions at 200 kWh. The solar and hybrid-solar wind scenarios have the lowest emissions because they are made up of 82% and 96% of renewable energy sources respectively. The wind-diesel scenario shows some emissions at 200 kWh, which come from the fact that the share of wind is only 49% in that scenario, and so the diesel component is responsible for the emissions.

Table 4.18 Emissions of Hybrid Scenarios at BE of 200 kWh/month

| | Diesel | Biomass (Equivalent) | Solar | Wind | Solar-wind |
|---|---|---|---|---|---|
| % Renewable Resource | 0% | 53% | 82% | 49% | 96% |
| Carbon dioxide (kg/yr) | 3,539 | 1,883 | 481 | 1,390 | 116 |
| Carbon monoxide (kg/yr) | 8.73 | 4.67 | 1.19 | 3.43 | 0.29 |
| Unburned hydrocarbons (kg/yr) | 0.97 | 0.52 | 0.13 | 0.38 | 0.03 |
| Particulate matter (kg/yr) | 0.66 | 0.35 | 0.09 | 0.259 | 0.02 |
| Sulfur dioxide (kg/yr) | 7.11 | 3.78 | 0.97 | 2.79 | 0.23 |
| Nitrogen oxides (kg/yr) | 77.9 | 41.65 | 10.6 | 30.6 | 2.55 |

In Table 4.19 below, the emissions from the stand-alone scenarios at 200 kWh/month are shown. The diesel-only scenario is the same as in Table 4.19 but the other scenarios reflect the contribution of their respective energy sources by themselves. The biomass-only scenario shows a significant reduction in emissions when compared to the diesel-only scenario, and does not emit any sulfur dioxide at all. As expected, the solar, wind, and solar-wind scenarios to do not have any emissions at their final point of use. However, as shown in the review of lifecycle assessments in Chapter Three, they do have emissions during other phases, in particular, the manufacturing stage of the technologies.

Table 4.19 Emissions of Stand-alone Scenarios at BE of 200 kWh/month

| | Diesel | Biomass | Solar | Wind | Solar-wind |
|---|---|---|---|---|---|
| % Renewable Resource | 0% | 100% | 100% | 100% | 100% |
| Carbon dioxide (kg/yr) | 3,539 | 8.16 | 0.0 | 0.0 | 0.0 |
| Carbon monoxide (kg/yr) | 8.73 | 0.31 | 0.0 | 0.0 | 0.0 |
| Unburned hydrocarbons (kg/yr) | 0.968 | 0.03 | 0.0 | 0.0 | 0.0 |
| Particulate matter (kg/yr) | 0.658 | 0.02 | 0.0 | 0.0 | 0.0 |
| Sulfur dioxide (kg/yr) | 7.11 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nitrogen oxides (kg/yr) | 77.9 | 2.74 | 0.0 | 0.0 | 0.0 |

### 4.5 Summary of Analyses

In summary, this chapter has applied at least four different aspects of the flexible planning approach outlined by Dr. Kai N. Lee to the problem of electrification in West Africa in four important respects. The first is in the adaptive approach to estimating the biomass resources based on residue harvest indices (RHI). The second aspect is with respect to the order of resource priority in AM, where the renewable energy resources that were modeled are in second place after energy efficiency and conservation (Principle #4). A third feature of AM that was used is the component sizing procedure that allowed for a range of minimum electricity requirements to be modeled for all three energy sources, as opposed to an intermediate forecast, that is, Principle #2 of Kai Lee's regional risk planning principles under uncertainty. Lastly, the fourth characteristic of AM that was used in this paper was the demonstration of cost-effective combinations of resources that allow for flexibility in planning in contrast to the traditional bias towards economies of scale (Principle #6).

The chapter has demonstrated the theoretical potential of solar and wind energy to surpass the energy demand in the region, as well as the potential for biomass energy from cash crop wastes to meet a sizeable proportion of the demand of those connected to the grid (demand forecast) in many countries, as well as meeting or surpassing the total demand shortfall in the majority of the countries, that is, including those who are off-grid. It has also shown the feasibility of progressively satisfying the minimum electricity requirements in non-electrified areas through a range of small scale technologies, in particular small wind turbines, solar PV panels, biomass gasification generators, and their associated components.

By satisfying basic electricity requirements of 50 kWh, 100 kWh and 200 kWh per month for households, as well as 400 kWh and 800 kWh for clusters of households, the analysis shows that West African countries can meet anywhere from 2% to over 300% of the total demand shortfall through distributed generation, with only a minority of the countries being on the lower end of that range. On average, the region could meet 16% to 64% of its total demand shortfall if each household consumed between 50 kWh and 200 kWh. This demonstrates that the distributed generation of renewable electricity could meet even more of the demand shortfall through an increase in consumption at the household level, as well as in commercial enterprises and even industries.

It should be noted, however, that the resources and technologies analyzed in this chapter do not exhaust all the possibilities for distributed electrification, but the availability of certain types of data made those identified here more amenable to modeling the AM planning concept that is the subject of this dissertation. For instance, the contribution of biomass electrification to the total demand shortfall could be increased considerably if all the cash crops were considered and if power were produced from these all year round rather than for a total period of six months, as was assumed in this study for the selected crops. Furthermore, electricity from pico, micro and mini-hydro power was not considered here, and neither were biogas digesters, which are currently being used, and that can utilize animal and human wastes as well as crop wastes.

The HOMER software was then used to analyze the cost implications of the various electrification options when compared to diesel generators, as well as on their own. The levelized costs of solar, wind and a combination of solar and wind energy are lower than diesel or biomass generators in the hybrid scenarios, mainly because of the high cost of the diesel fuel compared to the free solar and wind resources. However, in the stand-alone scenarios, the wind-only scenario is the most expensive of the renewable-only scenarios, including biomass at high levels of energy consumption. In addition, some of the modeling results in the hybrid scenarios showed that the use of batteries to store part of the electricity from a diesel generator can be cheaper than relying on the diesel fuel alone or a renewable energy technology alone, and in one configuration, it was the optimal solution. This can be attributed to the high capital costs of the renewable energy technologies, which contribute to a high LCOE, particularly at lower levels of consumption until such a time as the renewable energy contribution makes the scenario more cost effective.

Finally, the environmental costs in the form of pollutants were high for diesel, but very low for the renewable technologies and including biomass gasification, although no monetary cost or tax was assigned to pollution, which could further alter the results of the analysis. Thus, the chapter has provided a more tangible set of practical possibilities for electrification with respect to resources, technology and costs, that can better support or refute the more qualitative policy analyses presented in subsequent chapters. It has also demonstrated the feasibility of applying some of the core components of the AM philosophy to electricity planning in an off-grid setting in West Africa.

One caution that it is important to emphasize here with respect to the calculations is that the estimates of the amount of energy that is needed to meet the minimum basic electricity requirements, the demand shortfall, and the electricity potential from waste biomass are not precise figures as they depend on a number of assumptions about technologies or costs, for instance, which are both location and time dependent. Those figures have therefore been presented as whole numbers. On the other hand, the meteorological data for average wind speeds at a particular height and solar radiation is based on data that is recorded daily by NASA. Similarly the met demand is based on the actual amount of electricity generated by each country as recorded by the member utilities of the West African Power Pool. As a consequence, the presentation of physical data in the analyses reflect a higher level of significance because that is consistent with the level at which the phenomena were measured by the relevant authorities or agencies.

# Chapter Five

## Adaptive Management and Energy Policy in the U.S.A: A Retrospective Analysis

This chapter presents an analysis of the application of adaptive management (AM) to three ecological systems that involve electricity planning in the U.S.A., namely the Columbia River Basin, the Tennessee River Valley, and the Glen Canyon Dam. In these cases, AM has been used in planning for different lengths of time, in varying degrees, and with contrasting levels of legislative backing. The analysis of these case studies, in a retrospective perspective, is essential to this dissertation project because they represent the very limited documented instances of AM being applied deliberately and in some instances, explicitly, to energy planning. Thus, together, they provide an empirical basis for how this has been done and is currently being done, that then serve as a reference point for the subsequent analyses that are done in a more prospective manner for West Africa.

The chapter offers a more institutional and contextual analysis in the cases described to extend the insights from the previous chapter on modeling, which is necessary, but not sufficient for the implementation of an AM program. It is based primarily on policy documents that describe the management programs, as well as in-depth, semi-structured interviews with various planners and officials involved with the management of the ecological systems in the various regions of the U.S.A.

## 5.1 Columbia River Basin

The AM program in the Columbia River Basin was initiated when the U.S. Congress passed the Pacific Northwest Electric Power Planning and Conservation Act on December 1980, thereby authorizing the states of Idaho, Washington, Oregon, and Montana to form the Northwest Power and Conservation Council (NPCC) (U.S. Congress 1980). Three major crises that occurred between 1976 and 1980 were responsible for the passing of the Act, namely: 1.) the completion of all the main dams of the Federal Columbia River Power System and the realization that new power plants would need to be built to increase power supply; 2.) inaccurate long range forecasting by the Bonneville Power Administration (BPA) and regional electric utilities which led nuclear power plants already under construction to be shelved, and 3.) declining salmon runs in the Columbia River Basin, which was believed to be primarily due to hydropower development (NPCC 2012). A map of the Columbia River Basin is shown in Appendix B1.

The Adaptive Management program that evolved to address these crises then took on two main forms. The first was an AM program that focused on managing the ecological problems in the Columbia River Basin, in particular the biological functions such as recovering the declining salmon runs and the competing interests surrounding that issue, while the second was an AM program to manage the energy resources in order to meet the electric power demands of the region. Under the 1980 Northwest Power Act, the NPCC does a 20-year regional power plan that is renewed every five years with the $6^{th}$ Power Plan published in 2010 being the sixth iteration. The fish and wildlife plan also rolls over every five years with the latest plan being published in 2009. The Power Act has been amended only once, in 1996, in connection with the fish and wildlife plan. In addition to these programs being backed by congressional authorization, and the fact that the AM concept is ubiquitous in all of the Council's planning activities, one of its senior staff persons who also studied its application in settings beyond the Columbia River Basin has made the following claim:

> "No entity has played with the concept of 'adaptive management' more than the Northwest Power and Conservation Council".

According to another Council staff person, one important contrast between the application of AM to ecological issues and to electric power management is that while the underlying concepts of the framework were mainly derived from the intricate setting of fish and wild life and river restoration, it has been more successful on the power side. This is because biological systems are much more complex and less well understood, whereas the basic physics and economics of a lot of power generation are thought to be well known. As a result, there is less emphasis on the "learning" aspect on the power side than on the biological side. The NPCC does use an incremental approach on the power side as well, but while decisions may be reversible in ecological systems, they are difficult to reverse with power systems. This is because once a power plant has been built, the Council is stuck with the financial consequences of that decision for periods of up to decades. Thus, irreversible risk is very characteristic of decision making under uncertainty in the power industry.

However, before AM began to be applied to power planning, the Pacific Northwest had built a low cost hydropower system and transmission system on the main

Columbia River and on its tributaries starting in the 1930s, but mainly in the 1950s and 1960s. When electricity demand started to rise rapidly in the 1960s and 1970s, the Bonneville Power Administration (BPA) became concerned that the region would need new resources, which at that time meant thermal resources. A Council staff person explained that in what amounted to a “backroom deal”, the BPA decided to fund five nuclear power plants at once through an initiative called the WPSS (Washington Power Supply System), but only one plant was built to completion and currently runs, two were mothballed and two were never built, according to the staff person cited above.

The single nuclear plant that was completed cost as much as the rest of the power system, which is based on federally-built hydropower, and yet it only contributes five to ten percent of the overall power. This resulted in a financial disaster that caused the region to be burdened with the world’s largest municipal bond default, with the BPA having to take over the bonds. Fifty years later, the region still has to pay $800 million a year for nuclear plants that were never built. It was out of this crisis, then, that the realization came that there needed to be a very public regional planning process that could think through these issues, do this power planning in a different way, which was why the Council was created in the first place.

It was at around this time, mainly in the 1970s, that scholars started writing about adaptive management and decisions under uncertainty, and Dr. Kai Lee, who was engaged with these ideas, took those concepts and applied them to power planning. The basic approach prioritizes conservation and energy efficiency in order to extend the hydroelectric resources, thereby leaving room to make adaptive decisions on other resources. However, in subsequent power plans, especially the 5$^{th}$ and 6$^{th}$ power plans, the

Council has developed a more complex modeling system known as the regional portfolio model (RPM) to provide guidance on what decisions, and what combination of resources are most cost-effective and least risky for the region.

From the earliest days of the NPCC, it has generally tried to do its power planning without assuming perfect foresight, which in the estimation of one of the Council staff persons, is implicit in a lot of power planning exercises. In other words, when most utilities do power plans, they are usually trying to minimize the total cost of various resources over a planning horizon by using a given mathematical optimization technique. However, implicit in that exercise is a supposition of knowledge of what fuel prices will be, what the resource requirements will be, and other such considerations. Thus, according to that staff person, the optimization approach is almost antithetical to decision making under uncertainty. What the Council did differently, then, was to make a business case for paying more for conservation because it could be implemented incrementally, fairly quickly, and one could see an immediate benefit from it. For example, when power prices are high, it is easier and faster to implement energy efficiency and conservation schemes rather than waiting for a new power plant with a long construction lead time to go into service, especially since circumstances may change very rapidly during that time.

The resource portfolio model (RPM) approach that the NPCC employs extends the conservation metaphor from the earliest power plans to other supply side resources. It also developed its computational risk assessment and management capability in the last two power plans: the fifth power plan released in 2005, and the sixth power plan that was published in 2010. The inclusion of a more robust risk analysis was, at least in part, a result of the addition of a new staff member who had the ability to model that aspect of the problem, and who thought that some of the risks had been underappreciated in the past. Two critical concepts that were introduced by the Council in the 5th power plan for evaluating the risk-cost tradeoff and for narrowing down the number of issues for more careful analysis were the "feasibility space" and the "efficient frontier".

The feasibility space is a distribution of all the feasible and alternative plans within the portfolio, that is, future actions that are controllable, such as siting and licensing preparations to construct various types of power plants, how much and what kinds of supply side resources should be licensed and sited and planned for, or the implementation of demand side mechanisms and other planning attributes. The removal of a given resource as an option for expanding capacity either does not increase costs, which signifies that other resources can substitute for that particular resource (zero risk), or the costs increases, with that difference being the risk value of the resource. The model finds those plans that have the lowest expected cost, which includes both resource costs and environmental costs, and the lowest risk, where the measure of risk is the average cost of the 10 % worst outcomes, that is, the 10% most expensive outcomes. The "efficient frontier" then refers to the combination of all such least cost outcomes and is a quantitative representation of the value of risk aversion.

In order to meet the twin goals of providing low cost electricity to meet future demand, and reducing the risks posed by uncertain events in the future, the NPCC has designed a resource strategy through the identification and analysis of a number of scenarios or studies. The sixth power plan (the latest plan), in particular, evaluates eight scenarios as follows: 1.) A 'Carbon risk' scenario that assumes a range of $0 to $100 per ton by 2030; 2.) A current policy scenario, which includes renewable portfolio standards

(RPS), new plant emission standards, and renewable energy credits, but no carbon policy; 3.) A 'no policy scenario' that removes current policy from the analysis; 4.) A 'no RPS' scenario, which includes carbon pricing risk but no RPS; 5.) A '$45 Carbon scenario', which is intended to achieve emissions reductions at a fixed price of $45 per ton rather than uncertain prices; 6.) A 'coal retirement' scenario that is designed to phase out about half of all coal generation between 2012 and 2019; 7.) The 'no conservation' scenario; and 8.) The 'Lower Snake dam removal' scenario, which explores both the cost and carbon impacts that would occur in the event that the four lower Snake River dams are no longer available to meet electric power requirements.

Each of the scenarios listed above evaluates 2,000 to 5,000 plans in the feasibility space and captures the costs of portfolios that adapted themselves to alternative scenarios. The model then uses a set of 750 demand "futures" with very different conditions to evaluate each plan. A future can be defined as a bundle of sources of uncertainty that describe the region's circumstances or assumed circumstances in every hour over the planning horizon of 20 years. These sources of uncertainty include, but are not restricted to, fuel prices, electricity market prices, capital costs, hydropower conditions, load growth, and in some scenarios, the risk of carbon pricing. Unlike the kind of uncertainty analysis that a lot of utilities currently do, which is related to past excursions or trends of electricity price, fuel price and other similar variables, the "futures" are extremely different one from the other and are really intended to capture a wider range of conditions such as changes in technology or changes in legislation, among others. An NPCC official summarized the model by explaining that what it is essentially doing is providing an option that is available to future decision makers to either pursue the construction of some power plants, for instance, or elect not to construct them, depending on the cost of the plan and other circumstances that they may find themselves in. It is in this sense, then, that the RPM model is adaptive and incremental.

Even though many people, including the Council members do not understand all the quantitative aspects of the modeling and its technical complexities, and may even doubt its outputs, the model has proven to be a useful way of thinking through the concept of planning under uncertainty. With respect to the nature and extent of public participation in energy planning in its AM program, the NPCC does everything it can in public, and the development of the power plan involves a wide set of public hearings around the region. In fact, the NPCC subscribes to the Federal Advisory Committee Act of 1972, which ensures that the advice given by various federal advisory committees is objective and accessible to the public. One official made the following statement in that regard:

"I can't even get my council members together without having a public meeting, without having it publicly announced".

So everything that they do is open for public scrutiny and this lends a great deal of credibility to the final work products.

However, since the system is complex and the issues are complex, there is very little participation from members of the general public per se, because even those among them who are interested do not necessarily take the time to participate directly. Instead, the public input comes primarily from people who are interested in those matters for a living. This constitutes a wide range of actors, including the utilities, other agencies that are involved in planning, official representatives of Native American communities, conservation groups, non-governmental organizations (NGOs), and local and state government officials.

Nevertheless, it does happen that members of the general public provide their input. For instance, in the 6th Power Plan, the issues of climate change and carbon emissions mobilized about two to three hundred people to the public hearings who wanted to talk about those specific concerns, even though that had not been the primary focus of the Council. So occasionally, there are issues that bring out a wider public, but even such people are typically motivated by being members of environmental groups such as the Sierra Club. In general, the way the NPCC reaches members of the general public is by providing a lot of publications and information online that are widely read, though it is not clear how many of them actually participate in the planning. There are also a lot of comments on the Council's work in the conservation and energy efficiency field by people who are working in those areas, but not very many by members of what may be termed the "general community" or the "general public".

In terms of striking a balance between the traditional "science of parts" and the management process, or the "compass" versus "gyroscope" interaction to use Kai Lee's terminology, one official stated that in the view of the NPCC, adaptive management is a particular way of using the scientific and technical information, as well as the management decisions. Technical and economic analysis plays a significant role in the power analysis because the Council's statute requires it to consider all the alternative resources, whether generating or conservation-based. It should also be able to map out how much the costs would be, which should account for the entire life cycle costs. Thus, the technical modeling exercises regarding resource integration are dominant in their planning, and provide the analytical foundation for the council members to base their decisions on.

Very often, this mode of operation causes varying levels of consternation among some council members who would like to shape policy in a more qualitative way, but who feel that they are driven too strongly by the technical analysis. For example, when the technical analysis showed that the least cost resource that could get the region through the next 20 years was spending a lot of money on conservation and energy efficiency, and that not too much needed to be spent on new generating resources, a few members of the Council were uncomfortable with that. But in the end, they had a hard time making decisions that did not rely on the framework of the technical analysis. Furthermore, the Council has a high level of respect for the technical work, and recognizes that for the most part, the work is independent of anybody's interest.

There have been a number of successes since the NPCC adopted AM as its paradigm for planning, but there have been challenges as well. One of the successes of the power plan is that it is fundamentally a very simple plan, and as a result of adopting it, the Pacific Northwest does not need many more energy resources than it already has, and might need some natural gas only later in its 20-year plan. New wind power plants are also being built due to all the Renewable Portfolio Standards (RPS) requirements, and are expected to come online soon. It is also flexible so that other than the Bonneville Power Administration (BPA), utilities can make individual decisions, such as to build new gas-powered plants.

In conformity with the order of priority for resource planning established by the 1980 Regional Power Act, the conservation and efficiency effort remains perhaps the most successful one implemented by the NPCC. The statement below made by a Council staff member, describes the magnitude of the accomplishment.

> "The thing really works in a way. We have the resources we've largely called for to be added, and especially the conservation and efficiency, is getting added and has gotten added. We've added over 45,000 MW of conservation over the last 20 years, and we've got another 25,000 [MW] coming in the next 20 years, and it's happening, and it has kept us… we haven't had to build a major generating resource here ever since we started doing this."

A related achievement is that the Council has made a strong business case for a "cost-effectiveness premium threshold" for conservation resources that went beyond wholesale energy market prices. This premium of conservation concept recognizes that there are other sources of value from conservation such as risk mitigation, capacity deferral and the reduced costs associated with the acquisition of Renewable Portfolio Standard (RPS) resources.

Another success that has emerged from the modeling effort is the adoption by other utilities of some of the concepts and techniques that the NPCC developed. One of these concepts, introduced in the fifth power plan, is the "efficient frontier", which is the kind of language that almost all utilities now use, according to one Council staff member. Many utilities now also speak of making explicit tradeoffs between risks and costs, and have adopted a risk measure developed by the Council called Telvar 90, which is the average cost of the 10% worst outcomes or most expensive outcomes that was explained in the description of the resource portfolio model (RPM) above. Before that, utilities would typically use more financial portfolio risk methods like standard deviation to do risk analysis, which, in the view of the NPCC staff member is demonstrably inferior to what are called coherent measures of risk like the Telvar 90. The rate of adoption of the more advanced risk measure has been slowed, however, by the fact that the model developed by the Council has not yet been extended to others who may be able to use it.

One of the principal challenges of applying AM to power planning, and one that the Council has always faced, is that there is an inconsistent understanding of what it really means to plan under uncertainty. Some utilities in the Pacific Northwest do not do any planning under uncertainty and plan their resources toward a single forecast. The others that try to implement a more sophisticated planning methodology employ concepts of risk and uncertainty that are still maturing, in the estimation of a Council staff member who is highly experienced with those types of analyses. Thus, in addition to the different sources of uncertainties that various utilities have to contend with, the Council has a significant challenge of communicating its approach to utilities. It must also provide them with assistance with respect to their plans, given their still developing understanding of risk mitigation, capacity deferral, and similar concepts related to uncertainty.

Another challenge is that it is a constant struggle to help utilities understand why up front investments in conservation and energy efficiency will be helpful in the long run in avoiding a potentially difficult problem. It is also a constant struggle to get some of the utilities to appreciate the need to make decisions that take the regional plan as a whole into consideration, while simultaneously being able to make other decisions on an individual basis, if that is required. As a result, in many cases, it is difficult to stay the course on the AM logic of how planning under uncertainty is done, while accommodating the various interest groups. For instance, Council members are currently faced with a tension whereby the Tacoma power plant in Washington State, which has built hydroelectric and natural gas plants, has a surplus, but utilities in Idaho cannot buy that surplus from other parts of the region because of transmission constraints (30:31). Thus, it is a challenge to always think regionally and with a long term vision.

## 5.2 The Tennessee River Valley

In 1933, the U.S. Congress passed the Tennessee Valley Authority (TVA) Act to ensure the provision of flood control and improve the navigability of the Tennessee River, to ensure the proper use of marginal lands and provide reforestation in the Tennessee River Valley, and to create a government owned corporation to manage U.S. properties (mainly hydroelectric power plants) in the vicinity of Muscle Shoals, Alabama (U.S. Congress 1933). In both its early and later years, the TVA's role in producing electricity remained dominant with 89.1% of the $150 million appropriation in the first four years being spent on large construction projects associated with power, navigation and flood control, 6.7 % on fertilizer and agriculture, and 0.08% on regional studies and experiments (Conkin 1983). After 1945, electricity use increased sharply, largely due to an aggressive campaign for rural electrification by TVA. However, the region had virtually exhausted its hydroelectric capacity by that time, and so the Authority began to construct coal-fired steam plants in the 1950s and later nuclear plants from the 1960s until the 1980s, when it had to defer a large portion of its nuclear construction program due to changes in the economy caused by the 1973 energy crisis, and begin to focus on conservation (Droze 1983). A map of the Tennessee Valley is shown in Appendix B2.

Outside of the TVA Act of 1933, the major documents that currently guide the Authority's planning activities are the Integrated Resource Plans (IRP) for power planning, the Natural Resource Plans (NRP) for ecological management activities, and the 2004 Reservoir Operations Study that was conducted in order to determine whether changes in the way that the Authority managed the Tennessee River System would produce increased benefits for the people of the Valley. While these plans all contain strong elements of monitoring, evaluation, assessment, and planning under uncertainty, the term "adaptive management" is only used explicitly for the operations at the Tims Ford Hydroelectric Plant and Dam (TFH) in Franklin County, Tennessee. The purpose of AM at this facility is to improve the habitat conditions of two federally listed endangered species, namely the boulder darter and the cracking pearly mussel, by modifying the water releases into the Elk River from the dam, which is used for the combined purposes of power generation, commercial fishing, flood control, water supply, and recreation (TVA 2008).

In designing the AM program, the TVA considered two alternatives that are consistent with the National Environmental Policy Act (NEPA), namely the "No Action Alternative" and the "Adaptive Management Alternative" (TVA 2008). The five key elements of the AM program are as follows: 1.) To modify the water releases from the Tims Ford Dam through a combination of sluicing (or channeling), spilling (or discharging), and generating flows through a hydro turbine in order to adjust the condition of the tailwaters flowing from the dam and maintain the suitable warm temperature of the water for endangered species in a way that is similar to that of a natural free-flowing stream; 2.) To use the AM process during a three month period to determine the appropriate non-generation flows, that is, only flows from sluicing and spilling, needed to meet the temperature goals; 3.) To leave unchanged the management of floods or other high flow events induced by rain; 4.) To operate the Tims Ford Dam in the months of November through April as it had been done in the past; and 5.) To monitor the effects of the dam operations in 1 through 4 above to determine whether or not they improve the water conditions and habitat to the point where the endangered species can be re-introduced into a particular part of the river, and if not, what additional measures may be needed that would benefit the species.

The AM program that is being implemented at the Tims Ford Dam as described above is focused on what Kai Lee calls the "technical practice" of AM (Hafemeister 2007), or what could be classified as the ecological part of the three components of sustainable development according to C.S. Holling, the others being the economic and social components (also see the triangle in figure 4 of Chapter One). However, the Tims Ford Dam AM program also requires the TVA to share the monitoring information with a multi-agency that is comprised of professionals from the TVA, the Tennessee Wildlife Resources Agency (TWRA) and the U.S. Fisheries and Wildlife Service (USFWS), as well as work with public and private land owners and grassroots conservation groups to improve habitat conditions on the Elk River and its tributaries (TVA 2008). The interaction with various groups on the ground addresses the social component of the sustainability triangle to a certain extent, although the multi-agency professionals currently dominate the effort.

According to one TVA official, the AM operations at the Tims Ford Dam described above came about as a result of a formal Endangered Species Act consultation with various state and federal groups that stemmed from the Reservoir Operations Study. Out of this consultation, came a number of "reasonable and prudent measures" for the protection and benefit of endangered species. One of these measures was to develop AM programs at the Bear Creek Projects in North Alabama, which do not generate hydroelectric power, the Wilson hydroelectric dam, and at the Tims Ford Dam. However, of these three, the only currently active AM effort is the one at Tims Ford, where the consultations with the U.S. Fish and Wildlife was completed in 2006, and the steering committee began implementing the changes around early 2007.

The Reservoir Operations Study (ROS) itself was a comprehensive study done by TVA in 2004 to evaluate whether any changes it made in its policies for operating the 35 dams and reservoirs that have a major impact on its water control system (out of a total of 49) would provide greater public benefits for the people who live in the Tennessee Valley (TVA 2004). Modifications in the reservoir operations policy, which determines how much water flows through the reservoir at different times of the year, and the timing and extent to which reservoir levels rise or fall, were intended to balance tradeoffs between competing end uses (TVA 2004). Twelve operating objectives were identified in the study, which included low cost and reliable electricity, endangered species, revenue from recreation, and the scenic beauty of the reservoirs. Policy alternatives, ranging from the base case (no change) to the summer hydro power alternative to commercial navigation alternative were then selected to evaluate each of the objectives. The last two alternatives, for instance, resulted in negative recreation revenues. Three different evaluations were performed on each of the policy alternatives, the first of which was with respect to objectives identified from the public scoping process, the second was to assess impacts on environmental resources, while the third was to determine the regional economic benefits (TVA 2004).

Perhaps the most interesting observation made by another TVA official about the Reservoir Operations Study was that despite the fact that he thought that the ROS was a good, clear, and largely successful adaptive scheme, it was never called an “adaptive management” program. In fact, he said, that phrase does not appear anywhere in the ROS study because it would have provoked a higher level of resistance to implementing some of the operational changes, than they faced. The quote below succinctly explains his view of why this is the case:

> “At the TVA, adaptive management is a scary concept to a lot of people, especially people who operate the power assets, because they interpret it as additional constraints on how they can generate power. It doesn’t always work out that way, but sometimes it does. There’s a justifiable caution on the part of our generation folks.”

Thus, in the case of the ROS, AM was used implicitly to do the work rather than explicitly, so that the planned changes could be implemented. In fact, some of those changes appear to have had really good environmental benefits since the ROS was done. For example, the official spoke about a severe drought that occurred in the Tennessee Valley in 2007 and 2008, which did not result in the negative effects on fisheries and mussel communities that had been expected based on the experience of other droughts. It was clear to him that this was due to the new river operations in place. Furthermore, despite some friction between the resource agencies and TVA due to conflicting goals, the program was successful in getting all the working parties to discuss the issues in order to achieve some common goals.

With respect to power planning, the TVA employs a scenario planning approach to address the region's power needs over a 20-year period in the face of changing economic conditions and other uncertainties associated with long term prediction. Under this approach, there are eight scenarios and five strategies in the latest Integrated Resource Plan (IRP) that was issued in 2011. The eight scenarios are as follows: 1.) Economy recovers dramatically; 2.) Environmental focus is national priority; 3.) Prolonged economic malaise; 4.) Game changing technology; 5.) Energy Independence; 6.) Carbon regulation creates economic downturn; 7.) Reference case from Spring 2010; and 8.) Reference case where great recession impacts recovery (TVA 2011). The five planning strategies reflect a wide range of business options that the Authority could adopt, with each strategy being evaluated across the first seven scenarios, thereby creating a type of (7 x 5) matrix. The five strategies are as follows: 1.) Limited change in current resource portfolio; 2.) Baseline plan resource portfolio; 3.) Diversity focused resource portfolio; 4.) Nuclear focused resource portfolio; and 5.) Energy Efficiency and Demand Response (EEDR) and renewables focused resource portfolio (TVA 2011).

As with the 2004 Reservoir Operations Study, there is no mention of adaptive management in either the 2011 IRP or in the final programmatic Environmental Impact Statement (EIS) attached to it. Nevertheless, there are elements of AM thinking in the IRP, although there are a few differences, when compared to the Northwest Power and Conservation Council's (NPCC) approach, where AM is referred to explicitly. The main similarity between the two is that the scenarios in the IRP define future potential conditions, which combined with the strategies that have multiple variables within each of them, yield many possible futures that are run iteratively in a computer model called

Ventyx. From a conceptual point of view, this can be thought to be similar to the 750 futures per scenario that the NPCC uses, based on its own internally developed simulation model. One main difference is that there does not appear to be a philosophically rigid order of resource priority in the IRP, as opposed to that set forth by the NPCC, that is, energy efficiency and conservation, followed by renewables, followed by cogeneration, and lastly, all other resources. On the other hand, the IRP does provide a guideline for each component of the planning strategy regarding the ranges of capacity that can be generated from various resources and the time frame within which they should be deployed, for example, how much, and when to expand the contribution of EEDR or nuclear energy in the portfolio.

One of the challenges of implementing the explicit AM program within the TVA, that is, at the Tims Ford Dam specifically, is that the Authority does not really have an AM working group, and so the efforts that have been done there have been on a part time basis. A related difficulty is that there are not enough employees trained in AM to handle these programs, partly because traditional colleges and universities do not offer that type of training, and therefore, it has to come through professional experience. In addition, AM programs like the one at Tims Ford are seen as “one-off” efforts and are not institutionalized within TVA.

However, the TVA officials involved with the project were satisfied that it had been worthwhile so far, especially with respect to the trout fisheries and the endangered species, despite only being five or six years into the process. They also thought that AM could work if it was applied well, as long as the initial hurdle of applying it could be overcome. The challenge of being able to sustain it then presents itself, and is one of the major barriers to the successful implementation of more AM programs. In response to a question about the successful ten-year AM program in South Australia, one TVA official gave the following statement as one of the reasons why it can be such an obstacle at the TVA:

> "… You mentioned decades-long work. Well our board members roll on and off every three years, and we have a different power management plan. Getting long term buy-in into AM is tough. Not only internally for TVA, but our stakeholders change. There are a lot of politics involved in what we do, with the Tennessee Wildlife Resources Agency, with the Tennessee Department of Environment and Conservation, a lot of times, their directives are based on their leadership, not necessarily on what they've been doing for the last five or ten years. So inertia in AM is hard to sustain."

With respect to the implicit programs where AM thinking has been used, the main challenge within the otherwise successful ROS program was that most of the participation came through a multi-agency working group with professionals from the state government and federal agencies. Thus, other than public interest groups that have a vocal constituency, such as the Tennessee Wildlife Resources Agency (TWRA), it has not been very easy for the public to participate, although a TVA official emphasized that they were trying to involve the public as much as possible and get comments from them. While the process of getting public input into the IRP was challenging because it is impossible to please everyone, the TVA did get good reviews from a diverse range of interests within the stakeholder review group. For instance, leading representatives of both the Tennessee Valley Public Power Association and the Southern Alliance for Clean Energy, a strong environmental activist group made statements indicating that they thought that the TVA had used a "fair and reasonable process" in developing the plan.

**5.3**

The Glen Canyon Dam was built by United States Bureau of Reclamation (USBR) on the Colorado River in Arizona, and was completed in 1963, and in subsequent years, installed additional generators at the dam. Following evidence by the Glen Canyon Environmental Studies Group of the USBR that demonstrated that the operation of the dam impacted downstream resources both positively and negatively, the Secretary of the Interior for Reclamation made a decision in 1989 to prepare an EIS to evaluate the impacts of the dam (USBR 2001). In 1992, the Glen Canyon Act was enacted, which required the Secretary to operate the Glen Canyon Dam in a way that protects and mitigates the values for which the Glen Canyon recreational area and the Grand Canyon Park were established, such as natural resources, cultural resources, and visitor use (USBR 1996). The adaptive management program at the Glen Canyon Dam was then officially established in 1997 by the Bureau of Reclamation of the United States Department of Interior (DOI) in its 1996 record of decision (ROD) (GCDAMP 2012). A map of the Colorado River Basin showing the Glen Canyon Dam is presented in Appendix B3.

The pieces of legislation described above were a response to a significant amount of controversy that had occurred during the late 1980s and the early 1990s with regard to the production of hydroelectric power at peak demand times, but from a dam that is at the head of an internationally significant national park, that is, the Grand Canyon National Park. According to a former official of the U.S. Fish and Wildlife Service, who had been responsible for coordinating activities on the Lower Colorado River for a long period of time, there had been large fluctuations in the water level resulting from the operation of the dam. This had been destructive to the beaches used by recreational rafters, as well as to some plants and animals. The situation had caused some conflict between the power producers and officials of the national park, some Native American peoples, the recreational trout fishers at the Lees Ferry site, which is the fishing and raft launching area at the beginning of the Grand Canyon National Park, as well as with other users of the Lower Colorado River. Thus, there was a need to form collaborative work groups where the various interests could have “round table” discussions, address the issues, and try to make recommendations to resolve them.

An Adaptive Management Working Group (AMWG) was therefore formed in September 1997, following a commitment that was made to establish it in the 1996 ROD, and in accordance with the Federal Advisory Committee Act (FACA) of 1972, which requires that any advice it gives as a federal advisory committees is accessible to the public, just as in the case of Northwest Power and Conservation Council. Its role is to develop a long-term research and monitoring program, and advise the Secretary of the Interior about future decisions with respect to the operations at the Glen Canyon Dam. These decisions, however, have to be in compliance with the National Environmental Protection Act (NEPA) of 1969, which requires that all federal agencies must consider the environmental impacts of their actions in their planning and decision making activities.

Along with its subsequent amendments, the 1996 ROD is the primary guiding document for the management of the Glen Canyon Dam. Prior to the formation of the AMWG, the goal of the ROD had already been clearly defined. It was intended to enable the Secretary to meet the statutory requirements for protecting the resources cited above, as well as to balance the various competing interests in the River Basin through an analysis of a set of reasonable alternatives. The nine alternatives that were selected in the EIS, included: 1.) The “No Action Alternative”, which provides a baseline for comparing impacts and maintains the historic pattern of fluctuating water releases from the dam of up to 31,500 $ft^3/s$; 2.) Allowing unrestricted fluctuations in water flow releases to maximize the production of power, that is, to maximize the power plant capacity; 3.) The “Adaptive Management Alternative”, which includes on-going monitoring and research; 4.) The protection and monitoring of cultural resources; 5.) Measures to reduce flood frequency; 6.) Establishing the appropriate flow and timing of dam releases for building riparian or riverine habitats, or for beach building, for example, by depositing nutrients to help restore the natural dynamics of the river, or depositing sediment at high elevations; 7.) Rebuilding a new population of humpback chub; 8.) Additional study of the selective withdrawal of warmer water from the upper levels of the reservoir that could increase the potential for spawning new populations of native fish and other endangered fish; 9.) Establishing criteria and guidelines for responding to emergencies in interconnected power systems, such as during earthquakes (USBR 1996).

The first two alternatives are based on unrestricted fluctuating flows, while the last seven are based on restricted fluctuating flows, which consist of high, moderate, “modified low”, and “interim low” flow rates. In the primary decision that was made by the Secretary, the modified low fluctuation flow was selected as the preferred alternative to be implemented. According to the ROD, this is because that option would significantly reduce daily flow fluctuations below the “no action” levels, thereby fulfilling the habitat requirements of native fish, benefitting sediment resources and other cultural and wildlife resources, while allowing room for the flexibility for power operations, although there may be a reduction in power production (USBR 1996).

In its response to public comments made on the final EIS, which was completed in 1995, the 1996 ROD stated that the preferred alternative allowed for experimentation with various steady flow rates, and that would enable the implementation of an adaptive management program. It should be noted, however, that there was a subset of the public comments that came from municipalities and other electric power user groups, which was not in full agreement with the preferred alternative because it entailed a reduction in peaking power. That group, which was comprised of about three per cent of the total number of comments received, nevertheless thought that the preferred alternative was a feasible compromise, and that the final EIS offered a good model for resolving complex environmental challenges among diverging interests. They also urged the government to preserve the adaptive management process so that the assessment of the scientists could stand (USBR 1996).

There have been a number of successes and challenges since the implementation of the GCDAMP. According to an official who had worked on the program since its inception, one of the successes has been that the decrease in fluctuation of water levels from reduced power production has resulted in a reduction in the erosion of beaches, while still being able to produce sufficient power to cities like Phoenix and Las Vegas. Another success has been the replenishment of certain endangered fish such as humpback chub as a result of the water in the river being a little warmer, which is probably due to reduction in the fluctuation of the water level, although the last point has not rigorously proven scientifically. The official's assessment of the outcomes of the adaptive management program at Glen Canyon is captured in the quote below:

> "…and please, here are my words on that. It's been successful. We haven't been completely successful in restoring those beach/riparian values that the national park service manages for, but we have been probably 60 to 70% successful. And when you consider that power is so important for all the municipalities, I think that results in me saying it's a success."

There have also been a number of challenges. One of them has been the financial cost of implementing the improvements to the environment that were designed by GCDAMP. It has been an expensive program, costing "probably millions of dollars", according to the former official. "It's cost them a lot of money", he said. In the view of that particular official, the management of the people involved and their various interests has been much more difficult than the management of the natural resources, and very difficult to maintain. The reason he gave was that it was important for the process to allow the stakeholders to feel that they were an integral part of the process, that they had been able to speak their minds, as well as communicate their thoughts.

### 5.4 Assessment of Adaptive Management in the U.S.A.

This section provides a summary of the cases described above and applies a set of criteria developed, described in Chapter One, to assess the suitability and effectiveness of AM to the three U.S. case studies. Table 5.1 below summarizes the three cases with respect to whether or not AM was used for power planning, for Fish and Wildlife, or whether or not it was institutionalized.

Table 5.1 Summary of Adaptive Management Case Studies in the U.S.A

| | AM for Power Planning | AM for Fish and Wildlife | AM Institutionalized? |
|---|---|---|---|
| Columbia River Basin | Yes, explicit in power plans | Yes, explicit in Columbia River Fish and Wildlife Programs | Yes, NPCC, Columbia River Basin Fish & Wildlife Program, Bonneville Power Administration (BPA) |
| Tennessee River Valley | No, but elements exist in 'scenario planning' approach of the Integrated Resource Plan (IRP) | Yes, explicit at Tims Ford Dam. Yes, implicit in Reservoir Operations Study (ROS) | No, Tims Ford Dam AM program is a "one-off" effort |
| Glen Canyon Dam | No | Yes, explicit in 1996 Record of Decision (ROD) | Yes, GCDAMP, including AM Working Group, Monitoring and Research Center, etc. |

The assessment of the three U.S. cases is based on criteria proposed by Gregory, Ohlson et al. (2006) for determining whether an AM program can appropriately and sufficiently address a particular problem. The authors, who view themselves as decision scientists, developed the assessment rubric because they believe that it is important to establish explicit criteria at the beginning of deliberations, that provide a basis for determining whether AM should be used in a given case. They think that this approach would separate "true" AM initiatives from those that select ad hoc criteria as the project evolves, in order to justify program actions, as is the current practice in many instances. While the study cited is a prospective analysis of whether an AM program should move forward, the assessment done in this section is retrospective and relies on the information and the judgments already given by the AM practitioners who were interviewed in this dissertation.

The different considerations for assessment and the specific criteria within them are discussed briefly as follows:

1. *Spatial and Temporal Scale:*
    *i.* Duration: Whether or not the timeline to obtain results is compatible with the requirements of the managers
    ii. Spatial extent and complexity: Whether or not AM is scalable from a small experiment to a larger one. That is, is it amenable to multiscalar analysis?
    iii. External effects: Whether or not the cumulative effects of management actions relative to baseline trends are sufficiently addressed in the program.

2. Dimensions of Uncertainty:
    i. Parameter uncertainty: Whether the statistical uncertainty associated with a given parameter can be determined and to what extent. For example, where there is a theoretical basis for selecting a particular distributional form to reduce uncertainty such as a Poisson distribution for random processes, or a lognormal distribution for multiplicative processes, is it possible to determine which uncertainties are most important, and tailor the AM design to focus only on uncertainties that can most likely affect management decisions?
    ii. Structural uncertainty: Whether or not functional relationships between ecological variables have been identified correctly. In other words, whether there is some

degree of confidence in the level of resilience of the ecological and social systems to be managed, and if so, how the surprise outcomes will be addressed.

iii. Stochastic (random, natural) uncertainty: Whether or not low-probability, random, natural, and other causal events that can affect the AM design and expected outcomes have been properly assessed. For example, if managers are not able to attribute an identified outcome to a specific plan, then the value of conducting "active" AM, that is, experimental trials, may be minimal. [4]

iv. Confidence in assessments: Whether the degree of confidence in the assessments that scientists and other actors make is high or low, and if it is low, whether additional techniques and expert judgment are able to help improve confidence in the assessment of a proposed AM design.

3. Costs, Benefits, and Risks:

i. Specification of costs and benefits: Whether or not all the costs and benefits have been documented and be communicated to the stakeholders in a way that is understandable

ii. Predictability / Magnitude of effects: Whether or not the data collected through AM effort can reliably predict any outcomes to managers.

iii. Multiple objectives: Whether or not the AM plans address interests of stakeholders other than just the scientists.

iv. Perceived risks of failure: Whether or not clear thresholds minimize or identify perceived risks to institutions and species.

[4] Note: See the literature review in Chapter Two for the distinction between active and passive AM

4. Stakeholder and Institutional support:

   i. Leadership: Whether there is explicit policy guidance for AM and whether stakeholders viewed AM as an effective means to deal with uncertainty.

   ii. Decision-making flexibility: Whether there is sufficient continuity and flexibility within the management structures to revise experiments with new information

   iii. Institutional capacity: Whether the staff or outside experts have sufficient analytical skills to design, evaluate and monitor AM programs.

   iv. Ability to avoid taboo trade-offs: Whether the proposed AM design involves any trade-offs that can be considered taboo by some stakeholders. For instance, not being able to creatively address trade-offs among protected values like that between an preserving endangered species versus meeting social objectives can undermine the feasibility of an AM program.

Table 5.2 Assessment of Adaptive Management Case Studies in the U.S.A. (criteria adapted from (Gregory, Ohlson et al. 2006)

| | Columbia River Basin | Tennessee River Valley | Glen Canyon Dam |
|---|---|---|---|
| **Spatial and Temporal Scale:** | | | |
| • Duration | X | X | X |
| • Spatial Extent | X | Y | X |
| • Complexity | X | Y | X |
| • External Effects | X | X | X |
| **Dimensions of Uncertainty:** | | | |
| • Parameter | X | X | X |
| • Structural | X | X | X |
| • Stochastic (random/natural) | X | Y | Y |
| • Confidence in assessments | X | Y | X |
| **Costs, Benefits, and Risks:** | | | |
| • Costs and benefits | X | X | X |
| • Predictability | Y | Y | Y |
| • Multiple objectives | X | X | X |
| • Risk of failure | X | Y | X |
| **Stakeholder and Institutional support:** | | | |
| • Leadership | X | X | X |
| • Decision-making flexibility | X | X | X |
| • Institutional capacity | X | Y | X |
| • Avoidance of taboo tradeoffs | Y | X | Y |

KEY
X: Criterion is not a significant barrier to continuing an active, experimental AM.
Y: Criterion needs to be addressed more seriously to move to active AM, passive AM could be more applicable
Z: Very difficult to address criterion to move to active AM, and even passive approach is a challenge

The predominance of X's and Y's in the assessment presented in Table 5.2 suggests that based on my understanding of their statements, the practitioners interviewed had a generally optimistic view about what their programs had accomplished and could achieve in the future across all the categories. This does not imply that they had identical perspectives or that there were no differences in their perceptions of specific aspects of their programs, but as a whole, my assessment as explained below reflects that they had a generally positive outlook on their ongoing AM activities.

For instance, in the category of spatial and temporal scale, the value Y was assigned to the Tennessee Valley under the "spatial extent" criterion because the AM program in the Tennessee Valley was essentially limited to the Tims Ford Dam area in its explicit form. Furthermore, even though the Reservoir Operations Study (ROS) can also be considered to be very close to an AM program, the fact that the term was never mentioned suggests that the other criteria assessment rubric in Table 5.2 cannot be applied explicitly either, and so in alignment with the rubric, the "spatial extent" criterion would need to be addressed more seriously, thus the selection of "Y". This logic also explains the "Y" for the criterion of "complexity", but for "external effects", "X" was chosen because the baseline scenarios (No AM) at the Tim Ford Dam were well defined for the various parameters under examination when compared to the alternative scenario (AM).

Under the class of "dimensions of uncertainty", parameter uncertainty and structural uncertainty are assigned "X's" across the board because the documents show that AM was helpful in understanding and identifying the parameters that were uncertain, and the respondents demonstrated a high degree of confidence in the level of resilience to be managed. In the case of stochastic uncertainty, the Tennessee River Valley and the Glen Canyon Dam were assigned "Y's" because some of the respondents stated that they were not sure why certain actions seemed to lead to certain desired effects, and that those relationships still required more active experimentation, implying that the passive form of AM was currently more applicable. One example given by a GCDAMP official was that there was not a clear scientific explanation between their management of the Colorado River at warmer temperatures and the reduced fluctuation in the water levels on one hand, and the increased numbers of humpack chub fish on the other, but that their actions seemed to be working. Similar comments were made with respect to the trout fishery and endangered species in the Tennessee Valley, which was also assigned a "Y" for the criterion of "confidence in assessments" because the AM program at Tims Ford is only five or six years old, and thus fairly early in its process.

The criterion of "predictability" in the "costs, benefits and risks" category was given "Y's" across the board because all the respondents acknowledged that while they benefitted immensely from the information from the scientific experimentation, the success or failure of the proposed actions depended much more on buy-in from the stakeholders. The selection of "Y" for the "risk of failure" criterion in the case of the Tennessee Valley is mainly related to the recent nature of its AM program. A "Y" was also assigned for the "institutional capacity" criterion in the "stakeholder and institutional capacity" category in the Tennessee Valley because AM is not currently institutionalized at the TVA and many more professionals still need to be trained to build the capacity to implement the existing AM program. However, the Tennessee Valley was assigned an "X" for the "avoidance of taboo tradeoffs" criterion, while the others were assigned

“Y’s”. This is because the TVA officials that were interviewed expressed the view that the issues around their AM program were not as contentious as those at the Glen Canyon Dam and in the Pacific Northwest, although that situation would likely change if the on-going drought in the Valley continued.

In summary, this chapter has described the nature and type of adaptive management programs that are currently being undertaken at three different geographical regions in the U.S. It has discussed the various legislative actions that support the AM efforts where applicable, the institutions responsible for its operation, the successes and challenges of implementing AM, and whether or not AM is used implicitly or explicitly and under what conditions. The chapter has also provided an assessment of the three cases based on a rubric, which gives approximately equal weight to both the technical aspects and the institutional or participatory aspects of an AM program. This appearance of symmetry among the criteria may not be justified, however, given that all the respondents interviewed thought that getting a certain level of agreement among stakeholders was the most challenging aspect of pursuing an AM program. Thus, while the assessment rubric helps to make explicit those criteria that should be addressed in a clearly defined AM program, it does not in itself provide a final judgment on the effectiveness of environmental actions more generally.

# Chapter Six

## Adaptive Management and Energy Policy in West Africa: A Prospective Analysis

This chapter analyzes three settings in three different West African countries wherein the production of electricity production, ecological considerations and social concerns make them amenable to the application of adaptive management. Thus, even though the term "adaptive management" is seldom used in West Africa, the three selected cases have the characteristics of complex ecosystems, which have the potential of being managed through AM. The analysis of existing AM programs in the U.S. presented in the previous chapter serves as a comparative frame of reference for looking at the potential for adaptive management in a West African context. The chapter addresses the third research question asked in this dissertation on whether, and to what extent AM is being used to manage issues associated with electric power production in the region, and part of the fourth research question about how the social, economic and political conditions there might support or challenge AM.

The first two cases that are studied, the Volta River Basin and the Komadugu-Yobe River Basin, are like the Columbia River Basin, multipurpose ecological systems. They already provide a significant amount of hydroelectric power for several countries in West Africa, in the case of the Volta River Basin and the Komadugu-Yobe River Basin is also being considered for that purpose, they provide water for irrigation, and there is a need to protect endangered species. The development of these two river basins also has important implications for the communities that live in those areas and the diverse interests of various stakeholders with respect to the government-sponsored projects.

The third case is a center that has several branches across West Africa that applies its research on integrated methods for sustainable agriculture to tackle problems of energy, environmental preservation, and social development in a holistic manner. More importantly, it explicitly advocates for its own holistic philosophy of sustainability - a viewpoint that is, at least in principle, consistent with the three axioms of AM according to Norton (2005), which include experimentalism, spatial and temporal multiscalar analysis, and a commitment to localism or place sensitivity. Semi-structured and in-depth interviews with representatives of organizations and other reference materials are the primary sources of the data employed in carrying out the analysis. The chapter helps to answer the third research question in this chapter on whether or not AM is being used to manage issues associated with electric power production in West Africa, and to what extent it is, if it is in fact being used.

## 6.1 Volta River Basin

The Volta River Basin is the ninth largest river basin in sub-Saharan Africa and covers six countries namely, Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, and Togo. The governments of these countries jointly administer the Volta Basin Authority (VBA) through an executive directorate, a council of ministers in charge of water resources, a committee of experts, and a forum of the parties involved in the basin's development (VBA 2012). Approximately 85% of the basin is located in Burkina Faso and Ghana, while the four other countries share the remainder of the area of about 400,000 square kilometers (IUCN 2012). This section mainly focuses on the institutional and management perspectives from the Ghanaian side because in-depth interviews were obtained from respondents in that country. A map of the basin is shown in Appendix C1.

There are two main hydroelectric dams on the Ghanaian side of the Volta River Basin, and a third is still under construction. The first to be built and the largest is the Akossombo Dam, which was completed in 1966, and the second is the smaller Kpong Dam, which is downstream for the Akossombo Dam, and was commissioned in 1982. The third important dam, the Bui Dam is said to be 70% to 80% completed, according to a respondent, and is expected to be commissioned in 2013. The Volta River Act was passed by the Ghanaian parliament in 1961 in order to establish the Volta River Authority (VRA) as a government corporation responsible for the generation, transmission, and sale of bulk electricity from hydroelectric resources in the Volta River Basin (VRA 2012). While the first two dams are controlled by the VRA, the Bui dam will be controlled by the newly established Bui Power Authority (BPA), which was established by the BPA Act in 2007 (BPA 2011). Both authorities are also responsible for fishing, water transportation, and tourism.

When the Akossombo Dam was being built in the 1960s, soon after Ghana's independence in 1957, the main concern was transitioning from an agrarian society to an industrial one. At that time, environmental issues were hardly taken into consideration although, social issues, particularly resettlement schemes, had been given significant attention since the beginning of the project. As a consequence, there are many outstanding environmental issues, but social issues also remain today. Prior to the construction of the Kpong Dam, and now the Bui Dam under construction, Environmental Safety Impact Assessments (ESIA) were commissioned by the

Environmental Protection Agency (EPA) of Ghana that spelled out issues of community participation explicitly. This has also become a formal requirement of funding organizations such as the African Development Bank (ADB) or the World Bank, as recorded in their documents. In fact, the World Commission on Dams even goes beyond the mere requirement of community participation, and calls for a negotiated approach instead.

Despite the formal statements in official documents by both the national and international agencies involved with the planning and managing of the dams, civil society organizations claim that the implementation of the ESIAs on the ground has generally been weak. In the case of the national agencies, part of the reason lies in the inadequate institutional capacity to manage the systems thoroughly, but another reason lies in the tendency to reduce the environmental issues to technical problems. For instance, the Volta River Authority only had an engineering department for a long time, and it did not establish a specialized environmental department until the year 2005. In addition, the Volta River re-optimization project, which is intended to better balance power production with other functions of the river, such as irrigation, fishing, or tourism, only began in late 2005 and early 2006. Although the recently established Bui Power Authority is establishing mechanisms to address socio-environmental problems, one leader of an umbrella civil society organization said that they had the impression that the problems are reduced to calculations in order to avoid dealing with an uncertain future. As a result, the Bui Authority’s policies tended to be designed in isolation rather than in the context of national and international policies.

As a result of the low level of coordination between the power authorities and other government agencies on one hand, and communities on the other hand, several socio-environmental problems have occurred, and their resolution is a continuing challenge. For example, according to the director of an umbrella civil society organization in the Volta River Basin, there is an on-going lawsuit against the Bui Power Authority by communities whose lands were inundated by the construction of one of its dams, and who have not been compensated for their losses. The director, who holds a graduate degree in natural resources and biodiversity management, and has advanced training in integrated water planning management and social policy, stated that in a number of cases, the government preferred the people to move so as to gain access to the resources where they live. However, the BPA's compensation plans are not concrete in terms of when and how they are disbursed, and even those people who have been moved to other locations have experienced problems.

This widespread situation in the Volta River Basin generally speaking, required the communities to have a round table forum where all the concerned parties could come together, try to resolve their differences, and ideally collaborate in management activities. One such forum was the National Dam Dialogues (NDD), which was begun through a civil society initiative, and was founded in 2005, although the actual structure came into place in 2006. It consists of a secretariat, 60 forum members, and 16 National Coordinating Committees (NCC). These committees serve as the management body of the platform and are validated by the secretariat, which in turn, only implements what has been decided by the forum.

The 60-member forum is organized by different institutional categories as follows:

1.) Government department ministries and agencies such as the Ministry of Energy, the Water Commission, and the Ministry of the Environment.

2.) Operators, such as the Bui Power Authority and the Volta River Authority.

3.) Civil Society Organizations such as the Volta Basin Development Organization, Non-Governmental Organizations (NGO), and the Media.

4.) A local level structure, for instance, the government of Ghana is currently implementing a policy of administrative decentralization, so that the residents of the area surrounding the Akossombo Dam belong to a district assembly, which serves on the platform.

5.) Dam-affected communities as a category are also represented at the forum. It is estimated that in 1965, 80,000 farmers were displaced following the construction of the Akossombo Dam and were resettled into 52 communities. During the construction of the Kpong Dam, about 2,000 households were relocated into six townships. In total, seven new towns have emerged from the construction of the two dams.

6.) International financial and non-financial institutions, such as the German GIZ, formerly known as GTZ, the Chinese embassy, due to China's involvement in the construction of the Bui Dam, the Netherlands embassy, and the World Bank.

7.) Research organizations working on various environmental issues around dams, including the Volta Basin Research Project at the University of Ghana, Legon, the International Water Research Institute, and the Water Research Institute of Ghana, which is part of the Council for Scientific and Industrial Research (CSIR).

These seven categories of members are all represented at both the forum level and at the National Coordinating Committee level.

The ability of a citizen-led effort to bring together such a diverse range of stakeholders to address the many issues associated with the construction and management of hydroelectric dams in Ghana is itself a notable accomplishment. However, there have also been several successful outcomes of the National Dam Dialogues since its establishment. One is that they have helped to add to the existing knowledge about issues relating to dams undertaken by seasoned researchers, by bringing these scientists together with various stakeholders and having their research socially validated. The dialogues have provided a way to bring the dam-affected communities together with the operators, without the conflict that is typical of that interaction. They have also been able to prevent some frustrated residents of these communities, who had threatened to sabotage the dams if their demands were not met, from doing so. As a result, the power authorities now look to the NDD to facilitate the exchange and flow of information, the lack of which is often at the root of the conflicts. While the parties act in good faith to a certain degree, when difficult problems arise and the operators cannot meet the demands of the communities, the NDD has been able to step in to help negotiate a middle ground. All of the activities around the negotiations were initiated by the Volta River Basin Organization, a civil society body that is one of the NDD forum member groups.

Another success is that the NDD has been able to produce a high quality and regularly updated website, a newsletter, radio programs and newspaper articles on the sustainable development of dams. In fact, it is the only surviving forum on dam dialogue of its kind in Africa, with the others having previously existed in South Africa, Nigeria, Togo, and Uganda. The NDD has now gone beyond the shores of Ghana and has gained the attention of ECOWAS, which has kick-started a large dialogue on water infrastructure development in West Africa and invited them to participate. ECOWAS was interested in their efforts because the waters have different national boundaries where political systems are different, and therefore it is important to have these dialogues in order to further promote resource sharing between countries. The "Autorité du Bassin du Volta", the Volta River Basin Authority in Burkina Faso has also invited the NDD for their technical expertise in order to provide insights into their management undertakings.

There have been a number of challenges as well since the NDD was established. One of the main problems they have faced is that they have often run short of the funding required to run the organization. The only funding that is consistent is what is needed for some of their current research, which consists of looking at the impact of the dams over the years. However, the meetings between the communities and the dam operators, which occur every two months, and the annual meeting of dam-affected communities all require financing. An NDD representative who was interviewed argued that it was necessary and appropriate for the government to make monetary contributions to these activities. Unfortunately, on one hand, the government requires that they come under a government agency to get assistance, but on the other hand, the other stakeholders believe that state funding would compromise the neutrality of the dams dialogue process. For its part, the NDD does not believe that the funding would compromise its neutrality because it has several funders, and its proposals are explicit. Another challenge is making sure that the feedback mechanism that coordinates the fifteen-member National Coordinating

Committee and the 60-member forum functions properly. In the words of the NDD representative:

> "How do you make sure that a representative of one organization goes back to report to his organization about what happened at a meeting? For example, the Chief Executive of the Volta River Authority is not always abreast of what's going on, or even the Minister of Works."

With respect to adaptive management, the concept is not being used as a planning paradigm in the Volta River Basin. However, joint workshops by local and international organizations have been held that mention adaptive management in the context of re-optimizing the Akossombo and Kpong dams, and restoring the livelihoods and ecological functions affected by them. One of the outcomes of these workshops was the publication of a project appraisal report entitled the "Reoptimisation and Reoperation Study of the Akossombo and Kpong Dams" issued by the Tunisia-based African Water Facility (AWF)[5] for the government of Ghana (AWF 2010). The study recommends the use of adaptive management (AM) to carry out experimental water flow releases from the dam that can help monitor the impact of various flows on fisheries, aquatic diversity, and on agro-ecology, including irrigation and farming, groundwater recharge and use, and other restoration objectives (AWF 2010).

In terms of its concept, the document cited above is very similar to the 1996 Record of Decision (ROD) that was implemented at the Glen Canyon Dam, but I have found no evidence of the concept paper being implemented in Ghana. Nevertheless, the NDD representative was very supportive of the idea of AM as a new management

[5] The African Water Facility (AWF) is hosted by the African Development Bank (AfDB) at the request of the African Minister's Council on Water (AMCOW).

approach that would seriously include the participation of people whose views are not typically taken into account. He also stated that because it is a holistic, rather than piecemeal approach to management, AM would help resolve many of the challenges in the Volta River Basin, especially if its tenets were adhered to.

### 6.2 Komadugu-Yobe River Basin

The Komadugu-Yobe River Basin (KYB), which is also known as the Hadejia-Jamaa'are-Komadugu-Yobe River Basin (HJKYB), is located in the Northeast of Nigeria, but is also a sub-basin of the Lake Chad Basin that is shared by four countries, namely, Cameroon, Niger, Chad and Nigeria. It covers an area of about 148,000 square kilometers and is drained by two rivers, namely, the Yobe River with two tributaries, the Hadejia and the Jamaa'are Rivers, and the Komadugu River, which explains the longer form of the basin's name (KYB Project 2012). There is also a wide floodplain at the confluence of the Hadejia and Jamaa'are tributaries, known as the Hadejia-Nguru Wetlands. The basin is situated in an arid zone where more than 400 communities make their living as pastoralists, as fishermen, from tourism, and from agriculture (IUCN 2008). Its area, which covers six Nigerian states, is marked by increasing tension between farmers and pastoralists due to the construction of the Kafin Zaki Dam on the Jamaa'are River in Bauchi State (IUCN 2008). Two other important dams in the Basin are the Tiga and Challawa Gorge dams in Kano State. A map of the basin is shown in Appendix C2.

The primary planning document that governs the use of water resources in Nigeria is the National Water Supply and Sanitation Policy of the Federal Ministry of Water

Resources that was adopted in the year 2000. It requires all the River Basin Development Authorities in the country to report the quantity of water they harness, buy, or sell to the ministry, and report other pertinent data regarding dams and water storage. There is no specific national policy document for the management of dams, but different states can modify the national water supply policy to suit local concerns. However, all dams belong to the federal government under the Federal Ministry of Water Resources. In principle, there is a partnership between the Federal Ministry of Water Resources and the Federal Ministry of Power, but one water resource professional and representative of a basin organization explained that the level of coordination between the two is low. This is because the dams are constructed by the water ministry, but the turbines are controlled by the power ministry. This results in a conflict of jurisdictional authority, which is partially responsible for the electricity supply problems that affect even communities that are located close to the dams. However, there is a newly established federal energy commission that has been established to address those types of issues.

According to the chairman of a consultative network of stakeholders called the Komadugu-Yobe (KYB) Project, who is also a hydro-geologist by profession and holds a PhD in that field, there has been an increase in participation in local planning in recent years due to environmental problems in the basin. This was not the case ten years ago, but he believes that there is an increased awareness across the country as a whole with respect to those issues. Another reason for the increase in participation is that there is a rising demand for water between neighboring states that share the river basin, and therefore, there is a greater need for them to resolve disputes and collaborate around the equitable distribution of that resource. It is to address these challenges that the KYB

Project was formally established in 2006 as a registered non-governmental organization (NGO) to coordinate a wide range of stakeholders, including the dam-affected communities, government agencies, and the other users of the river basin. It should be noted, however, that some of the members of the Project have been involved with that type of work for the last twenty years.

The long term goal of the KYB Project is to enhance the security and livelihoods of impoverished people through the demonstration, replication, and scaling up of restoration and sustainable management practices for water resources and ecosystem services more generally (KYB Project 2012). The KYB Project is characterized by two phases. In its first phase, it used a set of Integrated Water Resources Management (IWRM) practices and principles to develop a framework to guide an informed and broad-based decision making process in the KYB. The IWRM approach, which applies ecosystem management concepts to the development of solutions in the basin, were then demonstrated in the second phase through field projects that were scaled up to both nationwide and transboundary management efforts that brought benefits to the poor (KYB Project 2012). More specifically, the objectives of the second phase were to facilitate the learning that would be required to support stakeholders in implementing the basin's management plans, to build consensus and promote dialogue among stakeholders on river basin governance issues, to improve transboundary cooperation in the larger Lake Chad Basin, and to disseminate the lessons learned on best practices to similar initiatives (KYB Project 2012).

There have been a number of successes in the management of the KYB by the Integrated Water Resources Management (IWRM) Committee of the basin in collaboration with the activities of the KYB Project. One of the key successes is that they have been able to maintain the infrastructure in the basin even under unfavorable environmental conditions, especially since water from rivers had not flowed into Lake Chad for the 15 years prior to 2010. Secondly, they have raised awareness of environmental issues and mobilized the participation of six states (Kano, Jigawa, Bauchi, Yobe, Borno and Adamawa), as well as that of stakeholders at the local, national and international levels, irrespective of ethnic or religious affiliations.

In terms of challenges, the shortage of funds to implement management decisions has been a major barrier. According to its chairman, the KYB organization has been able to secure the equivalent of about $7 million through budgeting allocations from the federal government, but they need over $100 million to carry out the Catchment Management Plan for the basin. This plan is intended to improve decision-making around the normalization of water flows, stemming the loss of biodiversity, reversing the degradation of land and water, and connecting the sustainable use of ecosystem services to livelihoods (Afremedev 2006). The plan was reviewed in 2012 through consultative activities in order to improve all the management undertakings in the basin since 2006, but funding is needed to implement it.

With regards to electricity, there are no electricity generators at either the Kafin Zaki Dam located in Bauchi State or at the two other dams meant for irrigation, namely, the Tiga and Challawa Gorge dams located in Kano State. At present, the Kano State government has plans to generate about 30 MW to 40 MW of electricity from its two dams, and similarly, there are plans to produce hydroelectric power from the Kafin Zaki Dam. However, there is a debate in the areas around the basin about whether or not the dams should also be used to produce electricity since low rates of access and inadequate power supply remain a problem in that region. In spite of this situation, the chairman of the KYB Project does not support the use of the dam for electricity generation, but thinks that the basin region should investigate the possibility of using other cheap, effective, and sustainable sources of energy. He stated that it would be preferable to investigate the potential of solar energy or biogas to this end, but that it remained a critical challenge to find ways to deliver this type of energy in an affordable manner, particularly to indigent households.

At present, the members of the KYB Project are working to put the structures in place to establish an equivalent of the National Dam Dialogues in Ghana in order to increase the number of stakeholders and improve the quality of their participation in the management of the KYB. Nevertheless, the chairman of the Project insisted that substantively, what they are doing is comparable to what is being done in Ghana. Furthermore, although an adaptive management process is not explicitly being used in basin, the chairman of the KYB Project affirmed that one was needed and that they were applying an adaptive process in its broad and intuitive sense. However, he emphasized the point that it was important to begin by educating the local people about the nature of the environmental problems like climate change, and then trying to work out sustainable management practices.

### 6.3 The Songhaï Centre

The Songhaï Centre is an organization that was founded in 1985 in the Ouando District of the capital city of Porto-Novo in Benin, for the purpose of training workers, producing agricultural products, and carrying out research and development on sustainable agricultural practices (SONGHAÏ 2012). Initially, it was a vocational center for training young people who had been compelled to leave school for various reasons, but it now serves as a national network for farmers, has computing centers, a credit union, a center for environmental restoration, and most importantly, it espouses a particular philosophy of development (Nzamujo 2002). It advocates a view of the world, and of Africa in particular, that begins and ends in the field, with science as its guide, and a systemic or holistic approach to development that takes culture into consideration, while valuing open discussion and the sharing of experiences, both positive and negative (Nzamujo 2002).

Although its headquarters are located in Porto-Novo, it has sites in five other cities in Benin, namely, Savalou, Parakou, Lokossa, Kinwédji, and Kpomasse. As part of what it considers to be an expansion of the "Songhaï movement" through West Africa, it has also established two sites in neighboring Nigeria, with one in the town of Amukpe in Delta State, and another in Bunu Tai in Rivers State, in partnership with the government of that state. In May 2008, the Songhaï Centre was proclaimed a "Centre of Excellence for Africa" by the United Nations (UN), garnering the support of five UN agencies that were convinced by the value of the center's work. A year later, in 2009, it was designated a "Regional Centre of Excellence for the Development of Agricultural Entrepreneurship and Rural Growth" by the Economic Community of West African States (ECOWAS).

According to its director, who holds a PhD in engineering with a specialization in electro-optical devices and has advanced training in economics and in the biological sciences, the Songhaï Centre currently has plans to develop similar projects in fifteen different African countries, with a particular emphasis on being autonomous in energy production. The stated mission of the center is to promote a heightened sense of creativity and innovation that can increase the standard of living of African people generally, and more specifically, through the following five methods: 1.) By using local resources; 2.) By combining both indigenous and modern agricultural techniques; 3.) By teaching and implementing effective management approaches; 4.) By encouraging both individual and communal initiatives, and; 5.) By including diverse opinions in all management activities (SONGHAÏ 2012).

As the focal point of its vision for a sustainable society, the Songhaï Centre places rural development as a priority in order to slow down the rate of rural exodus toward the major cities, which are becoming overcrowded as a result. The director of the center was emphatic on the severity of the problem and the quote below explicitly articulates his point of view.

> "The key to African survival is broad-based development, which means we move away from the centralized planning around the cities to every local government area having to be socio-economically viable. Up till now, the de-centralization is only political administration-based. It is not viable. The result is that people are leaving the local areas, the rural areas, into the big cities. In West Africa, there is a 3.6% rural exodus. That is a time bomb. If you go to Lagos [Nigeria], it is growing, every part of it. If you go to Abidjan [Côte d'Ivoire], or anywhere, Africa is on the verge of exploding. So I call it… it's not even urbanization. It is what I may call "*bidonvillisation*", you know, the "*slumization*" of Africa."

In an effort to address this problem, the center has developed the "Songhaï Green Rural City Model" that will also help it advance what it calls "a sustainable socio-economic settlement for the millennium." The model includes crop, fish, and animal farms, village homes fitted with lights, a stove and a refrigerator, a cultural center, a school, a market, a hospital, a computing center, and a village or town industry center with small and medium-sized enterprises (SMEs) or industries (SMIs). All the components of the city are then linked to each other through water piping and inter-connections to electricity generated from biogas digesters that convert the crop, animal and human wastes, as well as electricity derived from solar energy. Indeed, the Songhaï Centre itself is a type of commune, which already very closely matches its green rural city model. The only notable difference from the model is that the center was still partially dependent on electricity from the national grid at the time of the on-site interview, although a platform was said to be in place that would make it 100% self-sufficient within a couple of years and capable of selling electricity back to the grid.

With respect to its economic activities, the Songhaï Centre runs an integrated system of production, made up of primary, secondary and tertiary sectors of production. The primary sector is viewed as the motor of rural development, and is based on animal, crop and fish farming, which are all integrated with one another under the principle that there should be no waste production. This sector then triggers secondary production, which consists of agro-industry and agricultural entrepreneurship more generally. It involves food processing, as well as the design, manufacturing and assembly of farm machinery. Lastly, tertiary production focuses on the marketing, commercialization and transportation of the products of the first two sectors. The director of the center called this approach "short sector food chain" development because it is deeply enmeshed with the local environment, which makes it cheaper and more environmentally sustainable than the conventional system of "long chain" development that relies on production and transportation over long distances. A schematic of the model is shown in Figure 6.1 below.

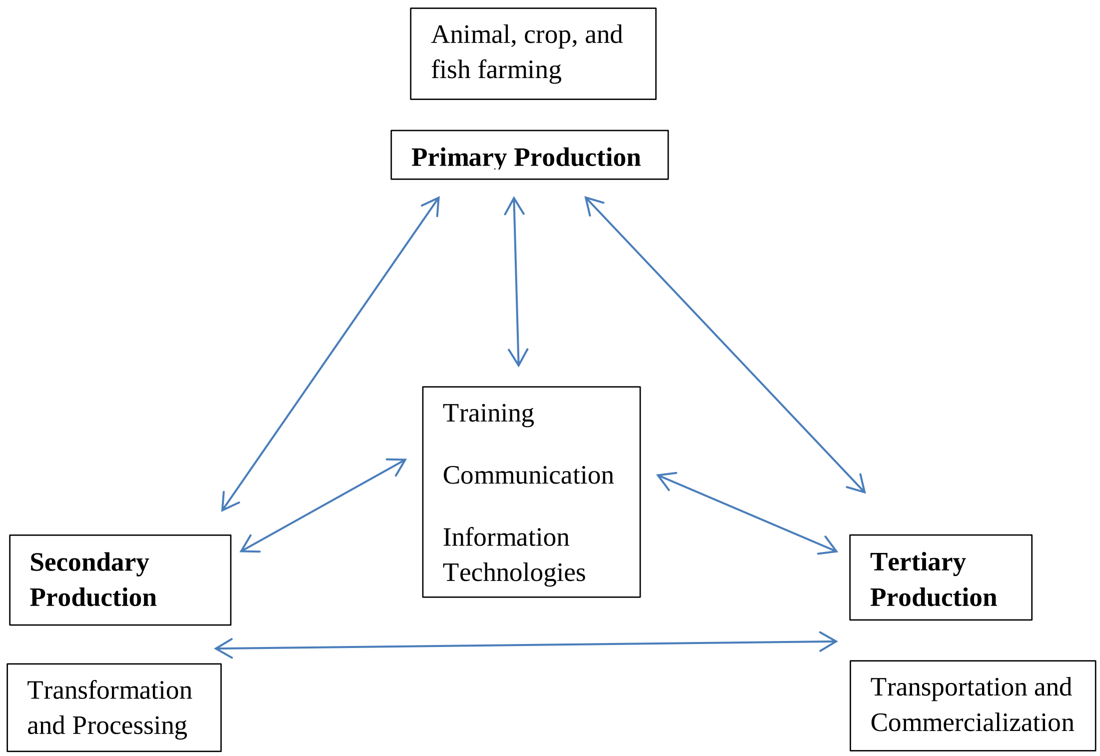


Figure 6.1 Integrated System of Production of the Songhaï Centre

Many of the programs and initiatives of the Songhaï Centre are consistent with the active form of adaptive management because of their emphasis on experimentation, learning, monitoring and feedback. On the ecological side for instance, a series of experiments were carried out for the biological control of pests that are harmful to the crops. A scheme was developed whereby auxiliary insects or predators that had been preserved under special conditions were then released onto a cultivated field to precisely remove unwanted pests such as white flies, green flies, and small worms. The preliminary results of these experiments, which were carried out at the Porto-Novo site, have been satisfactory, and the approach will be taken to other sites for further testing and application.

A more comprehensive initiative that has been adopted and implemented at the Songhaï Centre is the Zero Emissions Reduction Initiative (ZERI), which requires that all wastes or by-products from one sector be used as inputs in another sector. Under this initiative, the center not only converts all the animal excrements, plant wastes and sewage into biogas, but it also produces organic fertilizers and breeds insect larvae from this waste for various purposes. In addition, aquatic plants that are grown on its farms help to purify water from the fish ponds for irrigation, as well as to meet the center's energy needs as discussed below. Another of the center's efforts in both the primary and secondary sectors that feeds into ZERI is the ongoing applied research involving local farmers on crops such as the yam bean and the popular New Rice for Africa (NERICA) in collaboration with the West African Rice Development Association (WARDA). There is also the continuing development and testing of agricultural technologies at its appropriate technologies center to facilitate the cultivation of crops.

The Songhaï Centre's analysis of the energy problem in West Africa is based on a holistic view of the development challenge. Its director explained that according to projections from the UN's millennium development goals (MDGs), the region's economy would need to grow at a rate of 8% per year in order to meet those goals in 2015. In order to do this, agricultural production would have to increase by 6% per year, but neither the economic growth rate nor the rate of agricultural production can be attained unless energy use increases by 7%. If one considers the national centralized electricity generation infrastructure, irrespective of whether or not it is actually working, it would be impossible to provide access to most villages, which goes against the idea of broad based development. He believes that the key to this type of mass development is energy, and that to attain the critical figure of 7% increase in energy use, the solution for the region is to develop decentralized, modular systems, with renewables as the focal point.

A major component of the "Green Rural City Model" cited above in regards to electricity planning, is the concept of "sizing", which is the ability to tailor one's generation to either the energy resources or the financial resources available to purchase the relevant technology, or a combination of the two. This concept of component "sizing" has also been demonstrated more fully in the modeling exercises in Chapter Four of this dissertation. In the case of the Songhaï Centre, the main feedstock for energy production comes from biological materials, in particular wastes, because of their abundance. The director further explained the rationale for this in the quote below:

> "So we know that in Africa, our biggest competitive advantage is our biological strength, where the humidity and the temperature favor high biological activity, which means it can produce more, the end product, that is. We can easily get gas, which is natural gas, biogas, methane, with all the raw materials we have from the primary and secondary production. Look at, we're going to see now, we produce tons of chicken here, and the waste, 'what do we do with it?' The minute that we use it, we're going to see the new biggest biogas system people are talking about... we also have the pigs here, we have enough".

In addition to the animal wastes mentioned above, the center also grows a plant known as the water hyacinth that it uses for purifying the water in the ponds on the farm, but that can also be used for cleaning up stagnant water ways in many West African cities. The water hyacinths pull up all the nutrients, produce a high carbon/nitrogen ratio, and concentrate them into biomass, which makes them suitable for energy production from a gasifier, and at the same time useful as fertilizers in the form of the slurry. According to the director, these aquatic plants, which are plentiful in the area because of the abundance of sunshine, are the most efficient at harvesting solar energy. Thus, the center's silicon photovoltaic panels are not the only devices that can convert solar energy. The system of harvesting energy from aquatic plants at the center is known as the Neutral Energy Sink Harvester (NESH).

The overall approach to electrification in West Africa that is advocated by the Songhaï Centre is one that is bottom-up, and where communities can be galvanized around modular, independent energy. These communities would then become active zones that are conscious of their own generation capabilities, and their systems can then be synchronized with one another, and even sell electricity back to the grid when that becomes widespread. For example, if one community produces more of a given resource and another either produces less of it, or needs it at another time of the day, they can come into a partnership whereby they compensate for each other's weaknesses, negotiate, and work together in a democratic fashion. In reference to the 20-year ECOWAS master plan, the director argued that this was too long a period of time for people to wait for electricity and that there was no guarantee that it would actually accomplish its goals in the long run due to insufficient funding, inefficient planning, or any number of other reasons. Moreover, given the average life expectancy of the population, he underscored the point that it was imperative that efforts in the direction of the alternative approach, the modular approach, be intensified and be demonstrated to be successful, so that political leaders and policymakers could become more supportive of it.

### 6.4 Assessment of Adaptive Management in West Africa

The purpose of this section is to assess the case studies described above with respect to the extent to which they use AM or AM-related concepts in their management and planning activities. Table 6.1 below summarizes the three West African sites and categorizes them according to whether there is a system that approximates AM in place to manage power planning or environmental management or both, and whether or not this AM type of system is institutionalized at those locations. It reflects the findings from the cases described above that it is only at the Songhaï Centre that there is a system in place that is virtually identical to AM. This planning approach is being used at the center for both energy planning and agro-ecological management, and it is institutionalized in its charter as well as in its practices.

Table 6.1 Summary of Adaptive Management Case Studies in West Africa

| | AM for Power Planning | AM for Fish and Wildlife | AM Institutionalized? |
|---|---|---|---|
| Volta River Basin | No | No | No |
| Komadugu-Yobe River Basin | No | No | No |
| The Songhaï Centre | Yes, referred to as “sizing” | Yes, called integrated management | Yes |

In Table 6.2 below, the more rigorous assessment rubric that was used to evaluate the U.S. cases in Chapter Five in a retrospective perspective is used here again in a prospective manner. This is, in fact, consistent with the way Gregory, Ohlson et al. (2006), who created the rubric intended that it should be used, and is the way that they actually demonstrated its use in their publication. Table 6.2 assesses the three West African cases with respect to four main categories, namely, spatial and temporal scale, dimensions of uncertainty, costs, benefits and risks, and stakeholder and institutional support. Each category has specific criteria and the key that was used to assess them is explained at the bottom of the table.

Table 6.2 *Ex ante* Assessment of Adaptive Management Case Studies in West Africa. (criteria adapted from (Gregory, Ohlson et al. 2006)

| | Volta River Basin | Komadugu-Yobe River Basin | Songhai Center |
|---|---|---|---|
| Spatial and Temporal Scale: | | | |
| • Duration | Z | Z | X |
| • Spatial Extent | X | X | X |
| • Complexity | Y | Y | X |
| • External Effects | Y | Y | X |
| Dimensions of Uncertainty: | | | |
| • Parameter | Z | Y | X |
| • Structural | Z | Y | X |
| • Stochastic (random/natural) | Z | Z | X |
| • Confidence in assessments | Z | Z | X |
| Costs, Benefits, and Risks: | | | |
| • Costs and benefits | Y | Y | X |
| • Predictability | Y | Y | X |
| • Multiple objectives | Y | Y | X |
| • Risk of failure | Y | Y | X |
| Stakeholder and Institutional support: | | | |
| • Leadership | Y | Y | X |
| • Decision-making flexibility | Y | Y | X |
| • Institutional capacity | Z | Y | X |
| • Avoidance of taboo tradeoffs | X | Y | X |

KEY
X: Criterion is not a significant barrier to continuing an active, experimental AM.
Y: Criterion needs to be addressed more seriously to move to active AM, passive AM could be more applicable
Z: Very difficult to address criterion to move to active AM, and even passive approach is a challenge

The predominance of Y's and Z's in the assessment of the potential of the Volta River Basin (VRB) and the Komadugu-Yobe Basin (KYB) as sites that are amenable to the implementation of AM suggests that although not identical, in general, the criteria in both cases either needed to be addressed more seriously in order to implement an active form of AM, or it would be very difficult to implement AM at the two sites. In the case of the Songhaï Centre, it was assessed X's across the board because all of its activities reflect the presence of an ongoing form of active AM, and none of the criteria represented significant barriers to continuing those programs.

In the category of spatial and temporal scale, however, both the VRB and KYB were assigned X's for the "spatial extent" criterion because even though the investigation of the feasibility of AM in the VRB was done from the Ghanaian side, it was clear that the management efforts were transboundary in nature and this was recognized by ECOWAS, such that it asked the National Dams Dialogue to share their experiences with other stakeholders across the region. Even though the spatial extent of the KYB is squarely within the territory of Nigeria, the collaboration between the states concerned and between explicitly dedicated civil society organizations and government agencies shows that the spatial extend is sufficiently well defined for the implementation of AM, and it was therefore assigned an X.

The "duration" criterion was assessed Z's for both sites because it is difficult to assess the duration of possible AM programs given that neither of the management programs is sufficiently close to AM, nor has received any official sanction to manage all or part of the two ecosystems. The complexity and external effects criteria were assessed

Y's because while there is a high level of familiarity and recognition of the problems at stake by the civil society organizations, they are not yet in a position to address the complex interactions within the ecosystems. They are also not sufficiently staffed and funded to sufficiently monitor potential external effects, that is, the cummulative effects of management actions relative to baseline trends that could impact on those with the level of consistency required of an AM program. In the case of the Songhaï Centre, however, all the criteria in the category are assessed X's because the duration and spatial extent are well defined, the complexity is diligently managed and potential external effects are sufficiently well monitored that an AM program can be implemented without any difficulties.

With respect to the dimensions of uncertainty, the KYB was assessed Y's for parameter and structural uncertainty because it has a well-defined "catchment" plan that includes a strategy for ecological data collection, especially around the management of water resources and the need to combat desertification and protect biodiversity, as well as a policy framework and an action plan to achieve it. The VRB site was assessed Z's for those parameters because most of the efforts in that area revolve around stakeholder rights and participation rather than technical monitoring or data collection per se. In particular, the "Reoptimisation and Reoperation Study of the Akossombo and Kpong Dams" that was drawn up by the African Water Foundation (AWF) in 2010, and which mentions the need for adaptive management, does not appear to have had much, if any traction on the ground based on my interviews. Neither the VRB nor the KYB currently has good prospects for managing stochastic uncertainty or having confidence in rigorous assessments because the few existing plans and studies are still far from being implemented. However, the Songhaï Centre was assessed X's across all the criteria in the dimensions of uncertainty category because it has designed experimental programs that can control for uncertainty at the parameter, structural, and stochastic levels, in its biological pest control (parameter, stochastic) and waste management and reuse programs, for example, and it is possible to have a high level of confidence in its assessments.

In terms of the category of costs, risks and benefits, both the VRB and the KYB sites were assessed Y's because the criteria need to be addressed more seriously in order to move to an active form of AM, although passive AM is currently practicable in both cases because of the recognition of the multiple management objectives that need to be considered. The Songhaï Centre has the equivalent of an active AM program that systematically outlines the various costs and benefits, risks of failure, multiple objectives and has a high rate of predictability. Lastly, the Songhaï Centre was assessed X's across the board in the stakeholder and institutional support category because none of the criteria represent significant barriers for the implementation of AM given that it has a well-defined governance structure and good relations with the surrounding communities. Y's were assessed to the VRB and KYB in that category for the leadership and decision-making flexibility criterion because the civil society organizations at the forefront of pushing for improved management practices are not in a position to take leadership on management decisions. However, with respect to institutional capacity, the KYB project had a non-negligible level of support (though insufficient) from the Nigerian government and was assessed a Y, whereas the National Dams Dialogue in the Volta River Basin was required to come under the control of a government ministry in order to get any meaningful support and was therefore assessed a Z. The National Dams Dialogue in the VRB has strong relations with local communities that have strong indigenous values and leaders and has been able to bring them into the stakeholder consultations and was therefore assessed an X, while the KYB was assessed a Y because even though some members of the KYB project have been working with the dam affected communities for up to 20 years, their representative indicated that they still needed to increase the number of their stakeholders and more importantly, improve the quality of their participation in the management on par with what was being done by the National Dams Dialogue in the Volta River Basin.

### 6.5 Place-based Sensitivity

The purpose of this section is to address the third axiom of adaptive management, that is, place sensitivity, which requires managers to adopt "localism" or the specific context of a particular place, as the perspective that orients multiscalar management. According to (Norton 2005), localism should not simply be seen as a geographic location, but can best be thought of as "a negotiation between land and human culture" that necessitates the interaction between resource users, members of the general public, political leaders and adaptive managers on the basis of community-based values.

It is especially critical to be explicit about these values in a West African context because Lee (1993), for instance, clearly admits the conceptual but pragmatic bias of his work on adaptive management toward advanced industrial societies, although it has implications for emerging nations as well. West Africa, for instance, is characterized by an urban/rural divide with about 40% of the population living in urban areas, about half of which consists of the urban poor and the rural people largely living on their indigenous ways of life. Thus, AM is highly relevant to the urban society, which is modeled (albeit poorly) after the industrialized nations. However, it is also increasingly being reported in the literature that Traditional Ecological Knowledge (TEK), generally speaking, has certain similarities with AM because of the way it deals with ecological resilience in the face of pervasive unpredictability and its emphasis on feedback learning (Berkes, Colding et al. 2000).

Some of the similarities as well as differences between AM and TEK would therefore need to be made salient particularly with respect to rural electrification, and these would be subject to being resolved in the participatory process of the adoption of various energy technologies and managing their environmental consequences. Similarly, among the urban population where there is greater access to modern energy services, energy policy and planning should be based on an epistemology and set of environmental values that are historically rooted in the West African experience in the same way that the pragmatist epistemology of Charles Peirce, John Dewey or Aldo Leopold are the foundation for AM. This does not imply unanimity or the lack of contention among the diverse peoples of the region, nor does it imply closure to useful ideas developed elsewhere, but it does ground the process in a set of ideas or commitments that are easily recognizable and generally accepted by those immediately concerned.

I identify the three criteria discussed below as some of those that can be used to test whether or not given practices or policies are locally relevant, and can help to guide them. They include ownership and financing mechanisms, suitability as intermediate technologies, and environmental values.

### *6.5.1 Ownership and Alternative Financing Mechanisms*

The issue of ownership is very important in West Africa due to its status as an impoverished and economically dependent region. An analysis of the centralized projects of the West African Power Pool (WAPP) by Pineau (2008) showed that there is little evidence of West African ownership of its electricity sector whether in terms of financial investment, decision making, or accountability to its citizens. This is in part because, as explained in Chapter Three, the emphasis of the reforms of the electricity sector within the WAPP have been on the privatization of the national utilities, with a clear preference for large scale infrastructure promoted by the International Financial Institutions (IFIs) (Mebratu and Wamukonya 2007).

Furthermore, the majority of the funding secured for ECOWAS is spent through "International Competitive Bids" (ICB), which give local firms only a very small chance of competing with companies that are based in industrialized countries. For instance, out of $125 million earmarked for the Zone B-WAPP project, 85% (about $ 106 million) was to be spent through ICB (Pineau 2008). The WAPP funds were to be secured through large loans at least for the planned duration of the project and beyond, making it likely that the countries of the region will become even more indebted than they previously were unless the ensuing economic growth compensates for this situation (Pineau 2008). For this reason, it is necessary to investigate the use of more flexible financing options that could lead to ownership of the projects within a much shorter period of time as opposed to a debt burden that could last for several decades.

The micro-credit approach developed by NGOs such as the Grameen Bank, for instance, has been demonstrated to be an effective way of funding energy initiatives for the rural poor in Bangladesh and could be applied in West Africa (Biswas, Bryce et al. 2001). This was done by lending money to village organizations, which would repay their loans by selling biogas, solar or wind energy to wealthier members of the village thereby gaining ownership and control over the technologies and their applications (Biswas, Bryce et al. 2001). ECOWAS could also take on the role of helping to secure funding locally or externally for incubators where universities and technical schools collaborate with regional, continental, or international experts – an initiative that could lead to skilled personnel taking over the system thereby allowing external sponsorship to be phased out within five years or less (Blyden and Lee 2006).

Finally, Soumonni and Soumonni (2011) identify and discuss five alternative financing mechanisms that can be applied contextually to West Africa in order to increase the rate of electrification, particularly with respect to distributed generation technologies. These include: 1.) Indigenous financing institutions that can be termed rotating savings and credit associations (ROSCAs) and that are known as *ajọ* and *esusu* in Yoruba societies in Nigeria, Benin and Togo, whereby a group of people agree to make contributions to a fund and then all or part of the fund is given to the members in rotations; 2.) Village and cooperative savings account and credit institutions, which are more formalized and are regulated by national and regional agencies; 3) Remittances, which involve the transfer of funds by wealthier citizens living in urban areas or overseas to their poorer relatives in small towns or rural areas; 4.) Subsidies for rural electrification; and 5.) Investment funds for manufacturing and research.

### 6.5.2 *Suitability as "Intermediate" Technologies*

This criterion would seek to determine whether or not a given energy technology is suitable as an "intermediate" technology, which can be defined as one that is fairly simple understandable and suitable for repair on the spot (Schumacher 1993). It is more productive than most indigenous technology but is also much cheaper than highly capital-intensive technology. As a result, it lends itself better to providing meaningful employment, especially in rural areas, and is the precondition of capital, goods, or wages, which are the touted goals of development policy (Schumacher 1993). In deploying DG, the widely cited problem of storing electricity in DG is primarily a consequence of attempting to improve, recentralize and redistribute inherently diffuse energy flows such as sunlight or wind (Lovins 1976). While it is true that storage is difficult on a large scale, if done on a scale that matches most end-use needs, then daily or seasonal storage of low or medium-temperature heat should be straightforward with water tanks, rock beds or fusible salts at the point of use (Lovins 1976).

Another way of addressing this problem is through the use of hybrid devices such as solar-wind devices which combine a micro-wind hydraulic system and solar collectors and optimize their efficiency where both sources are available intermittently (Lovins 1976; Komerath, Venkat et al. 2009). All the energy from these sources need not first be converted into electricity in order to be useful to a given household or community. Windmills would work well for directly pumping water to irrigate the soil and supplying water to cattle in the many impoverished and semiarid regions such as the Felou or the Cayor in Senegal, for example (Diop 1987). Similarly, solar energy can also be used for water heating, drying and other applications.

DG technologies would also promote technological learning in the rural and peri-urban areas which would increase the penetration rate of the technologies, reduce cost and encourage innovation (Winkler, Hughes et al. 2009). One example of this is the development of Vertical Axis Wind Turbines for developing countries which takes advantage of local materials (e.g. bicycle parts for all rotating parts and PVC pipe for blades), local skills e.g. wood or metal working skills that are locally available and offers portability and accessibility (Komerath, Venkat et al. 2009). Such a DG technology as an intermediate technology would be ideal for further development at the Songhaï Centre's appropriate technology center.  Indeed, the director of the center in Benin stated that fostering this type of effort was one of his near term plans, as quoted below:

> "My dream is about 50 young Africans, crazy ones, working together to develop these technologies in our technology park. The government has just given us about four more hectares to develop it here, laboratories and everything. See the little things we're doing here… it's picking up."

Thus, such initiatives are more likely to promote adoption rather than direct technology transfer, which will encounter obstacles and end in failure unless they are adapted to the different socio-economic realities in the countries that aim to develop local capacity. Finally, in promoting his view of "Appropriate Technology", Schumacher argued that 'no system, or machinery or economic doctrine stands on its own feet: it is invariably built on a metaphysical foundation, that is to say, upon man's basic outlook on life, its meaning and its purpose' (Schumacher 1993).

### *6.5.3 Environmental Values*

This criterion would seek to determine whether or not energy policies are compatible with the dominant environmental ethos of both rural and urban communities in West Africa, as well as whether they are compatible with the values of the residents with respect to aesthetics, noise, smells, revered sites, etc. For instance, the main value system in traditional West Africa has been described in the literature as eco-bio-communitarian (Tangwa 2004) implying a communal societal ethos and a quest for balance with the environment. Another ethical paradigm, known as the "ethics of care" or "ethics of nature relatedness", is anthropocentric but recognizes that humans depend on nature for their survival (Ogungbemi 2001). When applied to energy policy, this ethic could inform the increased adoption of energy efficiency measures, energy conservation, and the promotion of benign technologies or 'technology with a human face' as used in the Appropriate Technology literature, for instance.

Another local perspective that is important to take into consideration is a historical understanding of what fundamentally constitutes a "nation" in an African, but more specifically, a West African context. In this understanding, what matters in the definition of a nation is not so much the place where a person was born, but the identification with the values that this place stands for (Yaï 2001). As a result, there is no contradiction in people claiming different nations for different purposes. This takes on added importance when it is considered that loyalties to ethnic and linguistic identities, which long preceded the formation of the modern West African states are still strong. Most of these nations in the long term historical sense, cut across two or more present-day countries, and should be better understood, respected, and employed democratically as building blocks for regional development generally, and for energy planning more specifically, particularly in trans-border areas.

## 6.6 Summary

In conclusion, this chapter has described the nature of three different ecosystems in West Africa that are amenable to adaptive management. One of these sites, the Songhaï Centre, already uses virtually all of the concepts of AM for both energy planning and biological conservation. One of the other two, the Volta River Basin has in its possession, a policy document that calls for the implementation of AM but this has not been attempted, while the other, the Komadugu-Yobe Basin already uses it as a conceptual tool for thinking about environmental management.

However, the fact that AM is initiated by civil society organizations in all three cases, undermines its ability to be more widespread as a policy model. Nevertheless, the effort remains worthwhile because of all the learning that is currently taking place, until such a time as they get more financial and political support from the national and regional authorities. The chapter has also discussed the possibility of emphasizing some place-based values that could help to improve the buy-in of management activities both on the ecological side and on the power side. It has addressed the third research question in this dissertation on whether, and to what extent AM was being used to manage issues associated with power production in West Africa by demonstrating that it is still limited in the region but there is at least one very good example of it, with many branches, and the others would welcome it. The chapter also sheds light on the part of research question four indicating that while civil society organizations were able to mobilize many of the stakeholders to improve the management of their ecosystems, the economic and political conditions continued to represent a challenge to the implementation of AM.

## Chapter Seven

## Learning and Innovation in Clean Energy in West Africa: Lessons from Denmark, China and South Africa

The purpose of this chapter is to provide an analysis of clean energy innovation in West Africa in comparative perspective with Denmark, a small industrialized country, China, a large industrializing country, and South Africa, which is the largest African economy but is one that has features of both an industrialized and a non-industrialized country. It addresses two aspects of this dissertation that have been highlighted earlier. The first is the set of basic outcomes that can be expected of an electricity sector, and the second is with respect to the economic component of ecological, economic and social components for sustainable development, which has not been sufficiently addressed by the founding theorists of AM as explained in the introduction to this dissertation.

In the first instance, the development of an innovation capability is critical in West Africa if the region is to adequately address its social, environmental, industrial and regional goals. For instance, developing this capability can enable the region to meet its social goals, particularly with respect to electricity access, or to meet its industrial goals of transforming its natural resource potential. Innovation can help address its environmental goals by helping to reduce its ecological footprint through adopting, adapting, and developing more affordable energy efficient and renewable technologies. And finally, innovation is a prerequisite for West Africa to accomplish its regional goals, which include increased ownership of the electricity sector as well as expanding its scientific, technological and innovation competence in maintaining, improving and expanding the sector.

Secondly, the chapter applies evolutionary thinking to the economic component of the triad of sustainable development in the sense that it does not assume either constancy or stability of fundamental relationship within and between the other components of the triad, namely, the social and ecological. Furthermore, it bases the analyses on a holistic view of interactions between actors, rather than emphasizing one particular aspect with respect to highlighting the increasing role that the development of clean energy will play in decoupling economic growth from the environmental pressures that arise from resource degradation and pollution. The Systems of Innovation framework, which like AM, relies on both an evolutionary approach and a systemic perspective, emphasizes the role of learning and competence building to development. It therefore complements the analyses presented in Chapter Six in the sense that it is consistent with the tenets of experimentalism, multiscalar management and localism in AM, and offers an approach to building the type of technological capacity that could enable the implementation of AM across various energy systems.

This chapter presents a brief overview of the role of clean energy innovation in sustainable development, with an emphasis on electricity generation, as well as some data that is relevant to environmental sustainability. It then discusses the various Systems of Innovation within the four jurisdictions, both with respect to the national or regional approaches to innovation, and with respect to clean energy. Lastly, it presents some lessons learned from Denmark, China, and South Africa that are applicable to West Africa. The chapter addresses the part of the fourth research question in this dissertation that asks what role innovation in energy technologies might play in the AM process.

## 7.1 Overview of Innovation for Sustainability

In 1970, a group of pioneers in the field of innovation published an influential report entitled the "Sussex Manifesto: Science and Technology to Developing Countries during the Second Development Decade", which advocated a systems approach to science and technology (S&T) for economic development, calling for a consideration of both demand and supply for S&T, as well as developing indicators and targets (Singer, Cooper et al. 1970). Forty years later, a "New Manifesto" was published by the STEPS (Social, Technological and Environmental Pathways to Sustainability) Centre at the University of Sussex, which called for a shift in STI thinking from a linear race to include poverty, social justice and environmental sustainability (Ockwell, Ely et al. 2010).

The main barrier to low carbon innovation, particularly in industrialized countries is the fact that their economies are based on energy derived from fossil fuels, which have become established through a process of technical and institutional co-evolution that is driven by increasing economies of scale that are dependent on this path (Unruh 2000). This creates a type of inertia against carbon saving technologies – a phenomenon known in the literature as "carbon lock-in" (Unruh 2000; Brown, Chandler et al. 2007). Although industrialized nations have the technological capability to address this problem, the institutional challenges are more complex.

On the other hand, in non-industrialized countries, Zerriffi and Wilson (2010) have recommended that clear policies to adopt modern and already available renewable energy technologies be pursued in order to enable non-industrialized countries to leapfrog over the previous "fossil-fuel energy route", but not penalize them for climate change. Much earlier, Goldemberg (1998) had made a similar recommendation, arguing that just as cell phones have reduced the need for land lines, likewise, clean energy technologies like photovoltaics (PVs) and Cathode Fluorescent Lamps (CFLs) in PV-CFL systems, would make connecting to a grid (often fossil-fuel-dependent) unnecessary.

A few studies on the adoption of PV systems in Africa, for instance, suggest that their adoption is growing but that it is greater in Southern and Eastern Africa, than in West and Central Africa (Cope, Aghdasi et al. 1997; Moner-Girona, Ghanadan et al. 2006). This increase in adoption in Africa has been primarily due to the reduction in worldwide PV prices as a result of advances in innovation in manufacturing and economies of scale in production. Unfortunately, the prices remain much higher in Africa than in other parts of the world, mainly because of the taxes and high transaction costs incurred in supplying the systems, except in Kenya, where reductions in the import tariffs as well as intense competition have lowered the prices (Moner-Girona, Ghanadan et al. 2006). My interviews in West Africa revealed that the Gambia and Cape Verde have also decided to remove import tariffs on renewable energy technologies. However, the prices would be significantly lower if the region invested in technological capability building and ultimately, innovation, such that some of the systems could be assembled or manufactured in the region. Table 7.1 below shows the socio-economic characteristics of three countries in comparison with West Africa, that have addressed innovation in energy technologies.

Table 7.1 Socio-economic characteristics of China, West Africa, and Denmark

| | **CHINA** | **ECOWAS** | **DENMARK** | **South Africa** |
|---|---|---|---|---|
| Population (million) | 1.35 billion | 262 million | 5.48 million | 50.11 million |
| Area | 9.6 million sq. km | 6 million sq. km | 43,098 sq. km | 1.2 million sq. km |
| GDP | $7,206 | $1,366 | $35,736 | $5,707 |
| R&D (share of GDP) | 1.49 % (2007) | 0.09 % (2005) | 2.57 % (2007) | 0.92% |
| Electricity Consumption (per capita) | 2,455 kWh | 88 kWh | 6,460 kWh | 4,532 kWh |
| Electricity Access | 99.4% | 19% | 99.8% | 84% |
| HDI Ranking | 89th | Most among 30 lowest | 19th | 123rd |
| Carbon Footprint (metric tons per capita of $CO_2$) | 5.8 | 0.25 | 8.3 | 10.1 |
| Clean Energy Technology Sales (Ranking) | 1st in biogas, 1st in wind turbines, and several companies in the top 10 in solar PV | N/A | 2nd (wind turbines) | N/A |

### 7.2 Energy Innovation in West Africa

At the continental level, the African Union (AU) and the New Economic Plan for Africa's Development (NEPAD) are attempts to establish a political and economic environment that could enable the diffusion of innovation and technological learning across the continent (Muchie 2003). It has published a document entitled “Africa’s Science and Technology Consolidated Plan of Action” and aims to enable the countries on the continent to apply STI to eradicate poverty, achieve sustainable development, and ensure that Africa contributes to the global pool of scientific and technological knowledge (NEPAD 2005). It has explicit principles and criteria for implementation, acknowledges the rich indigenous knowledge that exists outside of formal economic structures, and is generally in agreement with the New Sussex Manifesto in both substance and form. However, there tends to be a contradiction between formal/exogenous and informal/indigenous systems of innovation in much of development planning and the continuing challenge is to find ways to connect the two and expand their area of interaction (Bertelsen and Müller 2003). This tension has similarly been observed in the Adaptive Management cases in the U.S. with respect to the Native American communities as well as in Ghana and Nigeria with rural and peri-urban communities that can often be marginalized within those countries.

With respect to innovation in clean energy, the White Paper for a Regional Policy published by ECOWAS mentions building the human resources capacities of public and private actors, helping to mobilize financial resources for rural and peri-urban electrification, knowledge management, and the promotion of local production of energy goods and services (ECOWAS 2006). It also calls for the following innovation initiatives with respect to rural and peri-urban access, namely: the development of a feasibility study for an ‘Innovation and Development Fund’ and the determination of the size of this fund; the implementation of 200 demonstration projects including mature renewables and end-use equipment, of which there are six so far; and lastly, it calls for a strengthening of technological centers of excellence to promote the local manufacture of renewable and energy-efficient equipment (ECOWAS 2006). In order to implement these policies, ECOWAS inaugurated a new Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) in Cape Verde in July 2010 for the purpose of creating markets, formulating policy, and building capacity for the deployment of energy-efficient and renewable technologies (UN 2010).

With respect to the knowledge-based and technological training institutions in West Africa, the technical education that exists is focused on formal learning in formal institutions without practical application and little implementation with foreign firms (Adeoti 2002). There are a number of institutions engaged in research, development and demonstration (RD&D) in clean energy development, but there is no manufacturing capacity, and most of the activities can be described as learning, rather than innovation, in a strict sense. Many of these institutions are research centers that are affiliated with universities. Some of these include the Kwame Nkrumah University of Science & Technology (KNUST) Energy Centre in Ghana, the Sokoto Energy Research Centre at the University of Sokoto in Nigeria, the Centre for Energy Research and Development at Obafemi Awolowo University in Ile-Ife, Nigeria, and the *"Office de l'Energie Solaire du Niger"* (ONERSOL), a government research center for solar energy in Niger. Other institutions include NGOs, international agencies, and a few enterprises. The actors and networks involved in the innovation system include the trained technicians and researchers that are involved in research and the limited small number of users. The most important network is the *"Programme Régional de Promotion des Energies Domestiques* *et Alternatives au Sahel (PREDAS)"* – a regional consortium made up of six research centers, ministries, international agencies, NGOs, and enterprises.

*7.2.1 Energy Innovation in Practice*

In general, the implementation of renewable energy technologies outside of large hydroelectric power in West Africa is ad hoc and marginal. A number of country-level electrification schemes are underway, which mainly appear to be pilot projects through the efforts of NGOs, donors or private organizations, but government projects are not yet systematic or widespread (Blyden and Lee 2006). Although data is scarce on the rate of adoption of renewable energy in West Africa, there are indications of growing interest in it, mainly in solar PV applications. In Ghana, for instance, the number of PV systems grew from 335 with a total estimated installed power of 160 kWp in 1990, to 4911 systems in 2003, which corresponded to installed power of about 1 MWp or about 0.2% of the total energy supplied in that year (Kemausuor, Obeng et al. 2011). An overview of various international energy databases carried out during the course of this dissertation project similarly reveals that most West African countries barely register any production of renewable energy other than from large scale hydroelectric power. The interviews carried out for the dissertation research reveal, however, that Cape Verde has already achieved 27% of its capacity from wind energy, surpassing its target of 25% by the year 2015. The interviews at the headquarters of the Songhaï Centre in Benin revealed that the center is part of a platform known as the South-South Global Assets and Technology Exchange (SS-GATE), where countries in Africa and South East Asia, as well as China, India, and Brazil share certain inexpensive technologies and work together to develop solutions, such as modular, renewable energy technologies that the various countries have the capability to manage.

Furthermore, there are hardly any indigenous industries currently producing renewable energy technologies in West Africa, which could help to tailor them to the scale and types of needs that are characteristic of the region, and ultimately help to reduce their costs. However, the establishment of the first solar panel production line in the region was announced in January 2011 by the Sustainable Power Electric Company (SPEC) of Senegal, which bought a 15 MW solar production line from the Swiss company 3S Modultec, together with a comprehensive training package, a service and maintenance contract, and the certification of panels to be produced (Knaus 2011). SPEC, which already has a technology and innovation center that specializes in solar energy for the development of major projects, plans to expand the production line to 25 MW (Energy Matters 2011). It also expects to have the ability to combine automated and semi-automatic production stages, with experts from 3S Modultec assisting the local SPEC team to monitor the project throughout the planning, ramp-up, launch and certification stages (Energy Matters 2011).

Later in the same year, in November 2011, the Nigerian National Agency for Science and Engineering Infrastructure (NASENI) established a partnership with an unnamed foreign firm to establish a 7.5 MW solar module factory that would produce PV panels for small-scale off-grid applications throughout Nigeria (Beebe 2011). NASENI also disclosed that it ultimately plans to build a solar cell factory that can produce solar panels using locally grown silicon ingots (Beebe 2011). However, I am not able to confirm whether production has actually begun in either Nigeria or Senegal at the present time. One major advantage of these efforts at manufacturing, irrespective of whether they become rapidly successful or not, is that at an intermediary stage, they serve to make use of the ongoing knowledge development, research and training at the tertiary and research institutions mentioned above, and apply them in a local context. In this way, these initiatives could help to increase the rate of adoption and adaptation of even those technologies that are already readily available on the market.

### 7.3 Energy Innovation in China

One of the main criticisms of the aggregate level of analysis at the national level is that it tends to ignore or downplay the regional and industrial diversity within a nation, particularly in developing and transitional economies (Li 2009). In the case of China, however, its national science, technology and innovation (STI) policy leveraged the country's large market to require foreign companies to license a sector-specific technology to its companies as a precondition for their investment, but also required them to sell most of their products internationally in order to protect infant Chinese industry (Liu and Lie 2011).

Despite its high level of air pollution and increasing carbon emissions, China has made significant strides in clean energy innovation considering its fast rate of growth. In a set of studies of myths surrounding energy policy in the U.S, one of the myths that was identified is that developing nations are not doing their part in responding to concerns about climate change (Sovacool and Brown 2007). The specific study notes that one of China's numerous accomplishments is that it had been able to reduce its national energy consumption by more than 9% between 1997 and 2000 while GDP increased as a result of industrial energy efficient improvements (Wilbanks 2007).

Most rural villages in China now have access to electricity, with a successful DG program in small hydroelectric power (SHP), where the government provided capital subsidies and preferential tax policies, and modified the ownership structure from fully state-owned with poor profitability, to a diverse structure including shareholders, cooperatives and others (Yao and Barnes 2007). China's Renewable Energy Development Program (REDP) (from 2001 to 2008), set up by the National Development and Reform Commission (NDRC), the World Bank, and the Global Environment Facility (GEF), provided 402,000 solar home systems (SHS) with sales continuing after the subsidy ended (Xinlian and Wei 2008). The "Golden Sun" program initiated in 2009, which is based on competitive bidding, subsidizes 70% of off-grid systems and 50% of grid-connected ones and has already attracted a large number of projects (Martinot 2010).

China used a step-by-step strategy to develop its rural electrification program. In the case of small hydroelectric power (SHP) generators, it was guided by three principles, namely: self-construction, where local governments and populations were encouraged to use local materials, technology and water resources to build the systems; self-management, where investors owned and managed the stations, avoiding administrative interference and preserving the enthusiasm of the local communities to develop SHP; and lastly self-use, whereby the electricity produced by the stations were used locally, and the conventional grid was not allowed to compete in locally integrated markets (Yao and Barnes 2007). This corresponds to the concept of learning by doing, using and interacting

(DUI) mode of science, technology and innovation (STI). It also reflects the tenets of experimentalism, multiscalar management, and localism in AM.

As of 2010, China has become the largest supplier of wind turbines in the world, accounting for over 50 percent of new wind turbines, and adding nearly 19 GW of capacity in that year (GWEC 2011). One of the explanations for this rapid growth is that its wind industry emerged from other segments of its diverse industrial base that already had a high manufacturing and large scale project deployment capability (Lema, Berger et al. 2011). Because it is too expensive for one firm to develop all the expertise required for producing wind turbines, China took advantage of the relatively open innovation system that exists in the wind industry by using licensing agreements with European companies (joint design and collaboration instead of Foreign Direct Investment and trade) for its own learning and innovation (Lema, Berger et al. 2011). Furthermore, its dominant wind turbine producers, which are subsidiaries of state-controlled power generation firms, built up substantial in-house R&D capability, while benefitting from lower feed-in tariffs for service provision than foreign firms (Lema, Berger et al. 2011).

Thus, in the first instance China's original step-by-step approach to rural electrification is consistent with the tenets of AM, and it has allowed it to meet the additional social, industrial, and national goals that an electricity sector can contribute to realizing. It has also developed the STI capability in renewable energy technologies that can ultimately help it make its own eventual transition to sustainability.

### 7.4 Energy Innovation in Denmark

The NSI in Denmark is characterized by those of small rich countries with their higher degree of export specialization and greater fiscal autonomy, as well as fewer resources than large countries and less flexibility with respect to the flow of factor outputs such as labor migration, in and out of the country (Soete 1988). Also, the relative efficiency of the industrially oriented parts of their research system is explained by the close personal interaction between all the various sides of their research and production systems. While a few dominant multinationals in countries like Sweden and the Netherlands have been stimulating this interaction, in Norway and Denmark, public and private networks of engineers have exchanged information and cooperatively undertaken studies to prepare the ground for entrepreneurial efforts (Andersen and Lundvall 1988).

In Denmark, the engineering fields in which it has specialized reflects its traditional sector profile in agricultural products, going from grain production to butter and meat (Edquist and Lundvall 1993). However, its technological leadership in this industry was not based on random or serendipitous inventions, but on different clusters of incremental and radical innovations (Freeman 1988). For this reason, its successful innovation system cannot solely be explained in terms of R&D, but in terms of firm strategies, government research, the system of education, and other institutional factors as well (Freeman 1988).

A comparative analysis of the Danish and Dutch experiences with wind turbine development, for instance, reveals that the dominant mode of learning in the Netherlands was through learning by searching or the traditional “science-push” system of innovation predominantly based on subsidies for R&D, whereas in Denmark, learning by using and learning by interacting between the producers of turbines, users of turbines and the Danish Research Institute were privileged through investment subsidies for turbine manufacturers (Kamp, Smits et al. 2004). As a result, although both countries started developing wind energy in the 1970s, by the year 2000, the Netherlands had only one turbine manufacturer left out of ten to fifteen originally, with a total installed capacity of 442 MW (the target was 2000 MW), while Denmark had a cumulative installed capacity of 2340 MW with a thriving industry that produced wind turbines for the global market (Kamp, Smits et al. 2004).

In 2005, Denmark had the largest percentage of wind in its power grid (21.6%) and was a world leader in wind technology export ($7.45 billion) (Sovacool 2008). Following the 1973 oil crisis, a combination of taxes, subsidies, leadership, social, and cultural attitudes to R&D made success possible. From 1975 to 1988, the U.S. spent twenty times more, and Germany spent five times more in wind R&D than Denmark, yet the Danish have been more successful at producing wind turbines (Heymann 1998), and until China surpassed them in 2010, they were the top producers in the world. This can be attributed to Denmark's, slow, craft-based, bottom-up, incremental learning through experience, which proved to be more successful than "top-down" science-oriented approach. In fact a carpenter's wind turbine design, through artisanship, doing, using, and later help from more established scientific labs, emerged as the most successful and profitable one, which propelled Denmark to leadership in the sector (Heymann 1998).

With regard to the components of the clean energy innovation system that are necessary for its success, the knowledge and technological domain is made up of a highly educated population needed for both primary and secondary STI capacity.  The main actors involved were the Danish Energy Authority, which provided long-term financing of wind projects, interaction with users, encouraging local manufacturing, and open access to the grid. Also, the Riso National Lab is at the center of a user-producer network as well as does traditional R&D, all of which made it possible for the Danish company Vestas to lead the world in wind turbines manufactured, and in installation of offshore wind turbines for a long time, until it was surpassed by Chinese companies in 2010. Thus, the Danish case is a good example of a country making a technological and resource transition to sustainability through innovation, and in a way that both meets its energy needs and supplies the needs of an international market.

## 7.5 Energy Innovation in South Africa

Following the end of apartheid rule, the newly democratic South Africa that officially began in 1994 adopted the National System of Innovation (NSI), and formally made it a government policy in 1996, thereby making it the first non-OECD member country to do so (Maharajh 2011). Its current Ten-Year Innovation Plan, initiated in 2008, also uses the NSI language, and has the goal of moving the country from a resource-based economy to a knowledge-based one in order to address its "grand challenges", which include biotechnology, space technology, climate change, energy security, and human and social dynamics (RSA 2007).

The electrification program of South Africa, as one part of its overall energy policy, has shown remarkable results, going from a rate of access to electricity of less than a third in 1990, to over 80% in 2008, including more than five million newly connected households, by some estimates (Bekker, Eberhard et al. 2008). This occurred through a set of bold institutional and planning arrangements, as well as the development of technological innovations that were aimed at both reducing cost and achieving social goals (Bekker, Eberhard et al. 2008). The key institutional arrangement amounted to a socially-oriented policy for providing electricity access to the majority of the population that was previously deprived of it. The government abandoned plans to restructure and unbundle the electricity sector, and subsidized all of the connection costs for those who were close to the grid but were not connected to it. It also introduced a free basic electricity policy (FBE) of providing the first 50 kWh consumed per month free of charge to poor households, and it implemented an off-grid photovoltaic program based on concessions for remote rural areas (Bekker, Eberhard et al. 2008).

Two of the technological innovations that were introduced were as follows: One was the adoption of single-wire, single-phase lines, which are cheaper and more compatible with small loads than both the three-phase and two-phase lines that were previously in use. Another innovation was the development of pre-paid meters to reduce the cost of reading meters, of mailing bills to postal addresses, and to reduce the probability of non-payment and subsequent termination of service by allowing consumers to purchase the amount of electricity they could afford to consume in advance. Both of these innovations were implemented through a “blanket” electrification approach, also known as area coverage, where all potential consumers in an area are supplied with connections, rather than selective coverage, which only connects those customers who apply and pay for it (Bekker, Eberhard et al. 2008) .

However, in spite of its challenges in meeting its electricity demand, which is itself overwhelmingly dependent on coal, South Africa is significantly behind its renewable energy target of 10,000 GWh every year by 2013, intended to come from sources such as solar (both photovoltaics (PV) and concentrated solar power (CSP)), wind, and imported hydroelectric power (Yelland 2011). An important aspect of addressing these targets is the idea of increasing "local content" in the technologies themselves, and in November, 2011, the first wind turbine rotor blade manufacturing plant in South Africa was launched by a Cape Town-based company by the name of Isivunguvungu, which means "big wind" in the official languages of *isi*Xhosa and *isi*Zulu (Bretenbach 2011).

With respect to photovoltaics, Prof. Vivian Alberts of the University of Johannesburg developed a low-cost thin film solar photovoltaic technology based on Copper Indium Gallium diSelenide in 2005, but later licensed it to the German manufacturer, Aleo Solar (Ottery 2012). According to one observer of the South African energy industry, the inability for this invention to be produced domestically can be attributed to an inadequate institutional and legal framework, insufficient financing, and a lack of specialized solar PV manufacturing capability (Perrot 2012). Two of the main manufacturers of PVs in South Africa, Solaire Direct and Tenesol, are both subsidiaries of French-owned companies (Hirshman 2011).

Thus, South Africa, in the first instance, has relied primarily on policy innovations to expand electricity access, but in a second phase, it is trying to leverage its scientific and technological capacity to both increase access to remote areas and make a transition to a more sustainable economy through the development of renewable energy systems. Its efforts toward innovation in off-grid renewable energy systems in areas such as organic solar cells is still at the research phase, while its drive toward grid integration with renewable energy appears to be primarily policy-driven.

### 7.6 Summary

In conclusion, this chapter has demonstrated the use of systems of innovation concepts in the area of clean energy innovation. Both the China and Denmark cases showed that innovation in clean energy depended on strong national support, but targeted at that particular sector. China and Denmark also showed that learning by doing, using and interacting helped developed their small hydro power stations and wind turbines respectively, surpassing the production of countries that relied more on top-down R&D. Furthermore, China leveraged its position as a large country that is becoming wealthy, to diversify in various areas even within the area of low-carbon innovation. Its small hydroelectric projects (SHPs), and biogas innovation programs were aimed at its domestic market, mostly rural populations, but its advanced program in solar PV is aimed at the world market, although with a lot of local experimentation.

South Africa has demonstrated a strong learning ability in the way it increased its electrification rate in such a short period of time based on what can be considered to be the policy learning component of the overall concept of learning, as well as through learning by doing, using, and interacting (DUI). Nevertheless, it is investing heavily in R&D (learning by searching) in the area of renewable energy, but the linkages between this effort and the other sectors of the economy are still relatively weak. Therefore, it has an opportunity to leverage its relatively strong manufacturing base, even though it may be in sectors other than energy, to strengthen its learning by doing, using and interacting

(DUI) in the energy field. In this way, it can bridge the gap between its research and actual innovation that can help it to reverse its overwhelming dependence on fossil fuels.

ECOWAS has some good initiatives but should move away from the narrow form of STI to focus on more linkages within the wider economy. Rural electrification policy should be planned in coordination with other infrastructure needs such as schools, roads, hospitals and businesses, in order to foster as much complementarity and integration of such needs as possible, which could reduce transaction costs and multiply the spillover effects with respect to socio-economic benefits (Kirubi, Jacobson et al. 2009). It should also form more research and industrial partnerships with countries such as South Africa, for the purpose of enhancing its technological learning capability.

Finally, this chapter has shown that SI is a useful framework for planning innovation policy in the area of clean energy. It has argued that environmental sustainability and poverty reduction should be necessary parts of STI policy for industrialized and non-industrialized countries alike. If this research agenda is pursued, then the adaptive management and systems of innovation frameworks could be complementary and ideal tools for addressing problems of sustainability in highly intricate and complex social systems.

# Chapter Eight

## Conclusions, Policy Implications and Future Work

### 8.1 Conclusions of the Study

Given the ubiquitous issues of access to electricity and its consistent supply across West Africa, this work has been primarily motivated by the need to explore the potential for a holistic approach to electricity planning that could address these matters, rather than a methodology that is based on a narrow set of criteria. More specifically, the work has sought to address the need for an integrated energy-environment planning process that could guide ongoing and future electric power development efforts along a more sustainable path. Indeed, the dominant approach to power planning in the region has tended to emphasize technical and economic criteria to the detriment of environmental considerations as well as a number of social concerns. This dissertation has therefore employed the adaptive management framework as a theoretical tool to analyze the electricity sector in West Africa with a view toward contributing to a more systemic understanding of its strengths and challenges, and a more multidimensional appreciation of its possibilities.

The results of this study demonstrate the merits of applying a holistic perspective such as adaptive management to electricity policy analysis and planning in West Africa, as well as the obstacles that such an approach faces to its implementation in the region. The research questions that were posed in Chapter One serve as a guide to articulating the findings in this dissertation project. Chapters Three and Four address the first research question, which focused on how the currently dominant centralized approach to electricity generation could meet the regional demand, from a qualitative and quantitative perspective respectively. The findings of the analysis presented in Chapter Three suggest that those countries that adopted their own creative national policies and schemes for electrification, secured national or regional funding for them, engaged their respective civil societies, and adopted a wide range of policy instruments, were more successful than others at meeting the energy demands of their people. The two countries that were identified as having done this were Ghana and Cape Verde, which also have the two highest rates of access to electricity in the region and have well-performing utilities.

However, it is important to make a distinction here between having relatively high access rates and having a reliable supply of power. For instance, based on the data presented in Chapter Four, Senegal and Nigeria have comparatively high levels of access to electricity but both countries have had chronic issues with reliability for a long time. Until recently, Ghana had a stable electricity supply as it expanded electricity access, but it is beginning to face problems with reliability as well. Nevertheless, it is the judgment of this author that the results of the modeling exercises, which demonstrate the practical feasibility of distributed renewable electricity, combined with some of the best practices for the expansion of electricity access, are also adaptable to addressing the problems of reliability by complementing the existing power supply systems across the region. An additional point that should be made about the Ghanaian case is that despite a number of challenges, the bold and consistent, but flexible leadership that has been demonstrated thus far in the initiation and implementation of its 30-year National Electrification Scheme is a significant factor that helps to explain its successes.

On the other hand, those countries that either relied almost exclusively on the standard recommendation offered by the dominant international finance institutions

(IFIs), which is that of restructuring the electricity sector, or had no ambitious national rural and peri-urban electrification programs being implemented were not able to satisfy the electricity demand in their countries. This was the case for the majority of the other countries. The first part of Chapter Four also answers the first research question by presenting compiled data on the regional energy demand and supply, and the resources for meeting that demand, as provided by the West African Power Pool. It also shows the amount of the demand that is being met by each country and the “total demand shortfall”, that is, the demand that has yet to be satisfied, based on an extrapolation of the per capita consumption of electricity for a given country to the population that either does not have access, or has access, but is not sufficiently supplied. That analysis shows that the total demand shortfall is much larger than the met demand, and in many cases, four to five times as large.

Chapters Three and Four also provide responses to the second research question, which seeks to determine whether or not, and how distributed generation might satisfy the needs of people who are not currently connected to the centralized grid or who do not receive a consistent supply of power from it. Through a set of modeling exercises in Chapter Four, which followed the key elements of the adaptive energy policy analysis first outlined by Professor Kai Lee, I demonstrated that not only does the region have enough energy resources to meet its needs many times over, but that in practice, this can be done as well. I focused on the potential for solar, wind, and biomass energy from crop wastes to meet a set of minimum monthly electricity demand requirements in non-electrified areas. I also compared the cost-effectiveness and the amount of pollutants emitted from the electricity generated from these resources with those from diesel generators, which represent the default technological option in these areas.

The results showed that both hybrid configurations of diesel and renewable energy generators and stand-alone renewable energy systems can meet the minimum electricity demands of non-electrified or partially supplied households, and at the same time, meet a large proportion of the total demand shortfall in most countries. In a hybrid configuration of diesel generators with solar, wind and biomass energy technologies having a range of loads or demands intended for household energy consumption, the hybrid systems were cost competitive with diesel at lower consumption levels, and were cheaper than diesel at higher levels, where all the systems contained about 50% of renewable electricity. In the stand-alone systems, the modeling analysis shows that diesel generators become more expensive than renewable energy systems because of the fuel costs of the former. It suggests, however, that biomass generators become cheaper as the level of consumption increases and become cheaper than diesel at higher consumption levels, and that solar and solar-wind hybrid systems are cost competitive with diesel across all levels of consumption. Wind-only energy systems are the most expensive distributed renewable energy systems, in part because of the high capital cost of the turbines and relatively low average wind speeds, but even those are cheaper than diesel generators at higher consumption levels. With respect to pollutants, diesel generators emit the most, followed by biomass generators, which emit much less than diesel, and then wind and solar generators, which have no emissions at the point of their end use.

On the other hand, the reframed ECOWAS policy analysis in Chapter Three shows that the use of distributed generation to meet the energy demand of the population is currently limited and ad hoc in West Africa because it mostly consists of pilot projects by non-governmental organizations that are not mainstreamed into national policies. However, while centralized generation projects are overwhelmingly within the purview of national governments, the modeling analysis demonstrates that distributed renewable energy systems could be initiated and managed by households and communities. The civil society organizations involved with energy issues that were interviewed in this project reported that distributed renewable energy systems were ideally suited to help meet the electricity needs of non-electrified people, particularly if the communities could secure the financing and develop enough technological capacity to operate and maintain them.

In order to address the third research question, which asks if adaptive management is being used to manage issues associated with power production in West Africa, the study first analyzes three cases in the U.S. where AM had been used in varying degrees to help resolve challenges that were associated with the production of electricity. These cases were analyzed in a retrospective perspective in order to determine empirically, how and to what extent AM had been used in electricity planning, in order to provide a reference point for determining how AM or similarly related concepts were being used in West Africa. I found that the application of the concept of AM to energy planning is still limited, even in the U.S., where the idea originated. However, in those instances, its application has taken on two dimensions, namely, applying AM heuristics to ecological systems that are affected by power generation and transmission systems, and applying AM exclusively to the management of the resources for power generation.

The research conducted in this dissertation project revealed that the Northwest Power and Conservation Council (NPCC) in the Pacific Northwest had the most expansive AM program, which it applied explicitly to both ecological issues associated with the presence of a large dam, that is, fish and wildlife, and to the management of the energy resources themselves. The Glen Canyon Dam in Arizona had a program to manage the ecological issues associated with the presence of the dam, while the Tennessee Valley Authority (TVA) applies AM explicitly to the ecological issues at only one of its dams, the Tims Ford Dam. One of the findings, however, was that the TVA has a Reservoir Operations Study (ROS) that it started in 2002 to determine how changes it made in the operation of Tennessee River might provide maximum value for the people of the Tennessee Valley, but that the Authority does not refer to it explicitly as "adaptive management". The study evaluated the operations at 35 of its 49 dams and it was effectively an AM program on a comparable scale as that of the Columbia River Basin or the Glen Canyon Dam, but the term "adaptive management" was never used explicitly to avoid alienating the power systems staff who thought that the term implied reducing power generation.

The experience around the implementation of the Reservoir Operations Study at the TVA is related to another finding across the U.S. cases, which was that the biggest challenge of implementing AM and its greatest value was bringing a diverse set of stakeholders to the table to accept a collaborative framework for management, and to agree to a set of tradeoffs for managing the river systems that could be satisfactory to most of those affected. This in turn affected the length of time and the extent to which AM could be implemented in a manner that more closely matched a scientific experiment. One aspect of implementing AM that is not as complex, however, is in its direct application to power production at the NPCC, which is a more tractable problem because the economic and engineering principles are largely well understood. Thus, even though there were many observable benefits from applying AM, such as the improved preservation of endangered species, a more stable electricity supply system, or an increase in the availability of fish for various stakeholders, its value on the social side, that is, for collaborative decision making, was higher than as a purely scientific tool.

The U.S. studies and findings then set the basis for evaluating whether AM could be applied at three sites in West Africa. Two of these sites were river systems that are comparable to the U.S. cases, and the third was an agricultural training and research center involved with experimentation on sustainable agro-ecological practices and energy production, and which has eight established branches and a few others being developed across West Africa. One important distinction with the U.S. cases was that while the U.S. Department of the Interior (DOI) oversees and regulates all activities associated with ecosystem management, the efforts at collaborative management in West Africa were initiated by civil society organizations that brought the affected parties together to express their concerns about the management of their ecosystems. The civil society organization in Ghana that brought together the stakeholders in the Volta River Basin (VRB) on that country's side of the basin, for instance, had developed a high level of skill and ability to bring the diverse set of groups together. It was especially adept at helping the displaced communities and the rural communities affected by the dams to express their concerns and ensure their proper representation at public fora. However, it did not have the capacity or funding to implement an AM program like any of those in the U.S., despite the existence of a regional study that had called for the implementation of AM in the Volta River Basin.

The civil society organization that led the efforts at collaborative management in the Komadugu-Yobe Basin (KYB) in Nigeria had more support from the government, and had included more rigorous scientific assessments within its management efforts than the organization in Ghana. In fact, it had laid out an extensive management document known as the "KYB Catchment Plan", which is similar to the Reservoir Operations Study in the Tennessee Valley, but had not received sufficient funding to begin its implementation. However, the civil society organization in the KYB indicated that it needed to increase its stakeholder participation to be on par with that of the organization in Ghana. The Songhaï Centre in Benin was the civil society organization that reflected all the elements of AM both on the ecological side and on the power side. The close identification of its programs with AM was recognizable in the three following areas. First was in its integrated system of crop and animal production, in its Songhaï Green Rural City Model which includes energy production and an industrial center, and finally in its philosophy of development which was well-defined and explicitly stated, and has been discussed in Chapter Six.

One important observation was that across all three cases, the leaders of the organizations held advanced degrees in the sciences and had high level training either in additional scientific areas or in environmental management. Thus, not only were the West African sites amenable to the implementation of AM, but also, the capacity to initiate AM programs was also available through the presence of highly skilled and interdisciplinary professionals. However, none of the organizations had legislative backing, a government mandate, or government funding, which limited the scope and impact of their activities. This implies at least two possible outcomes for these organizations in terms of the long term sustainability of their efforts at collaborative ecosystem management.

On one hand they can continue their current activities but also try to get more government buy-in and financial support in the short to medium term so that their initiatives can become better institutionalized like in the U.S. cases. On the other hand, they could increase their capacity to implement management approaches that are similar to AM through alternative financing mechanisms and increased civil society support until such a time as they become influential enough to command the attention of the government. They could perhaps enlist the participation of sympathetic government professionals in their management activities, even doing so across national boundaries in the case of the Volta River Basin, for example. These are some of the ways in which the social, economic, and political conditions in West Africa might support or challenge the implementation of AM.

The second part of the fourth research question sought to understand what role innovation in energy technologies might play in the AM process. The U.S. cases of AM studied showed that at the TVA and the NPCC, there was an effort to invest in modern renewable energy systems to increase generating capacity and build more resilient systems, particularly at the NPCC where the Northwest Power Act requires renewables to be the next resource to be considered after energy efficiency and conservation. However, this was in the context of grid integration in large centralized power systems, and the adaptive managers were not directly involved in innovation issues. On the other hand, the extension of access to electricity to people in West Africa and the building of an infrastructure to serve that purpose suggest a need to invest in innovation in different kinds of technologies. All the civil society organizations expressed a strong interest in alternative approaches to electrification because of the slow rate of progress of the centralized approach in meeting the energy and access demands in most West African countries. However, only the Songhaï Centre had an active program that used and integrated renewable energy systems into its management activities (mainly biogas and solar energy), and sought out South-South collaborations to increase its technological capability in the area of renewable energy.

Although ECREEE, the regional energy efficiency renewable energy center, has now enlisted the assistance of three West African universities to do capacity needs and resource assessments, innovation strategies are limited in West Africa and are not included in electricity planning. I have therefore employed a comparative approach to determine how China, Denmark and South Africa used innovation to address their energy challenges. In particular, South Africa has been able to significantly address its electricity access challenges, China has both solved its electricity access challenges and diversified its resource portfolio to include renewable energy resources, while Denmark has made significant strides into its transition to a more sustainable economy through renewable energy. Furthermore, both China and Denmark have been able to establish themselves as global leaders in the manufacture of renewable energy systems thereby satisfying additional national objectives and priorities.

The analysis of the role of clean energy innovation in AM underscored the equivalence between the concepts learning in both AM and in the systems of innovation (SI) framework, and demonstrated the compatibility between the tenets of experimentalism, multiscalar analysis, and localism in AM with learning by searching, doing, using and interacting processes in the SI framework. The findings indicate a diversity of innovation schemes that reflect both the holistic management approach in AM and the systemic view of innovation in SI. For instance, China decentralized its national electrification plans and implemented them within its regions through a step-by-step approach that was based on local capacity building, Denmark also implemented its goal of manufacturing wind turbines by tapping into the ideas and skills of artisans and craftsmen, while South Africa used a combination of mandates and subsidies and relevant, cost-driven technological innovations to extend electrification. This diversity of lessons can be applied to the West African case, but most importantly, in terms of their gradual planning approach that promotes various kinds of learning, and in the identification and strengthening of systemic relationships between the various stakeholders.

Finally, the findings demonstrated that three out of the four combinations for electrification discussed in Chapter One and shown in Table 8.1 below were effective in their own contexts in terms of access and stability of power supply, and were more sustainable in terms of resources used and the ecological consequences of power generation. However, the combination of centralized generation and centralized management shown in first quadrant of the first column was the most difficult to manage sustainably in the absence of the effective decentralization of a centralized plan. This was a significant challenge for the West African Power Pool (WAPP), which currently relies exclusively on large scale hydropower and fossil fuels, and for the management of the Komadugu-Yobe Basin, where civil society organizations are currently opposing the construction of a large hydroelectric dam there for social and environmental reasons, and therefore the brackets in that quadrant contain a “No” for the first criterion, and a “No” for the second.

South Africa was able to extend access to power based on a centralized management system and on centralized generation, but has not yet been able to make a transition from its overwhelming dependence on coal, hence a “Yes” for effective planning, followed by a “No” for sustainability. Similarly the centralized hydropower generated in the VRB has been centrally managed and has increased access rates in Ghana and provided electricity to its neighbors, but the social and environmental consequences of power generation in the Basin remain insufficiently addressed, and hence the same assessment as for South Africa. On the other hand, China was able to successfully change its strategy from top-down implementation of its centralized plans to decentralized implementation in the specific cases of rural electrification through small hydroelectric projects and biogas digesters, and Denmark also did this successfully from the beginning of its nationally-planned wind turbine program. Both countries are shown in the second quadrant of the first column. Lastly, AM or AM-like concepts were found to be effectively applied to both centralized generation in the U.S. cases and to distributed generation approaches to electrification at the Songhaï Centre, to the extent that there was sufficient buy-in by all the relevant stakeholders.

Table 8.1 Effectiveness and Sustainability of Technological and Management Options for Electric Power Planning

| | Centralized Management(CM) | Adaptive Management (AM) |
|---|---|---|
| Centralized Generation (CG) | WAPP, KYB [No, No]<br>VRB, South Africa [Yes, No] | NPCC, Glen Canyon Dam, TVA [Yes,Yes] |
| Distributed Generation (DG) | China, Denmark<br>[Yes, Yes] | Songhaï Centre, Benin [Yes, Yes] |

With respect to the four hypotheses that were postulated in this dissertation, the first, which postulated that the use of AM principles in the parts of the Volta River Basin (VRB) in Ghana had led to more reliable power supply than in the Komadugu-Yobe Basin (KYB) in Nigeria where AM was not used, was rejected. The research showed that both had a similar degree of AM precepts being used with the KYB being stronger on the technical practice, while the VRB was stronger on stakeholder participation. However, the reliability of electric power in both countries was unrelated to the management of those basins, but was instead connected to aspects of their electricity policies themselves. In fact, the plans to construct dams for hydroelectric generation in the KYB have not yet been implemented and there is currently a debate there over whether the existing dams should continue to be used only for irrigation, or whether the plans for power generation should proceed.

However, the second hypothesis, which postulated that the low degree of interaction between political and economic stakeholders on one hand, and social actors on the other, would undermine social and policy learning, was validated in the finding that Ghana's Self-Help Electrification Programme (SHEP) was unique in the region and the implementation of other national plans was not decentralized in the same way. In virtually all the other countries, there is a very low level of public participation in electricity planning. While it is understandable that the general public, so to speak, is not typically well-versed in electric power issues, there are also very few civil society organizations that are in a position to engage these issues either, unlike at the Northwest Power and Conservation Council in the U.S., where a diverse array of stakeholder groupings regularly attend the Council's public meetings. In the absence of an effort by governments, such as with the SHEP, to enlist the skills, resources, and initiative of the users of electricity in planning activities, the type of learning that can be obtained over time is bound to be limited. This interaction between firms, users, and later, planners, could also be spearheaded by firms in an analogous manner as has happened with the telecommunications sector in Africa, but this experience is yet to be replicated in the West African electricity sector.

The third hypothesis, which postulated that the low level of domestic ownership of the electricity sector across West Africa negatively impacts the widespread implementation of its plans, was also validated because the electricity policies of most countries were limited to the restructuring and sector reform policies that are prerequisites for getting long-term loans from the international financing institutions as discussed in Chapter 7. In the case of Ghana, where multiple sources of funding were used and multiple policy instruments were deployed in addition to restructuring, the results were significantly better. The widespread lack of ownership across the region, therefore, tends to constrain it to the preferred management approaches and energy technologies of the funding agencies, as well as their timeframes. This situation promotes the implementation a rigid set of policies that undermines policy experimentation and learning, tends to minimize the level of buy-in and participation by most local actors, and largely ignores the particular socio-political and economic realities of the countries in favor of a pre-determined policy. On the other hand, the internal mobilization of the available human and financial resources in countries such as Bangladesh (discussed briefly in Chapter Six with respect to micro-credit), and China and South Africa (discussed in Chapter Seven with respect to innovation) was instrumental in spearheading the widespread implementation of their electrification plans.

The fourth hypothesis, which stated that the general condition of weak local technological capability promotes turnkey solutions to technological challenges that undercut the ability of the region to build an innovation system around renewable energy, was only partially validated. It was validated in the sense that this general condition promotes a certain level of inertia to innovation, but ultimately the hypothesis would be rejected because neither the countries nor the region were implementing policies or strategies to promote innovation. The only exception in the cases that were investigated was the Songhaï Centre, which is a civil society organization. With regard to this hypothesis, then, the comparative analysis of China, Denmark and South Africa demonstrated that the implementation of innovation policies and strategies helped them overcome their core electrification challenges, and in the case of the first two countries, they have been able to build a system of innovation around renewable energy.

The table below shows a summary of the hypotheses, evidence and conclusions made in this dissertation.

Table 8.2 Summary of Hypotheses, Evidence and Conclusions

| Hypotheses | Evidence | Conclusions |
|---|---|---|
| **H1.** The use of AM principles to monitor the environmental impacts of dams in the Volta River Basin (VRB) in Ghana has led to more reliable power supply, and better social and environmental conditions than in the Komadugu-Yobe Basin (KYB) in Nigeria where AM was not used. | Interviews, policy documents and the peer-reviewed literature showed that the relatively reliable power supply in Ghana was not related to AM in the VRB, since AM is not being implemented, strictly-speaking, in either the VRB or the KYB, but to Ghana's national electrification scheme. | Hypothesis rejected |
| **H2.** The low degree of interaction between political and economic stakeholders, and social actors undermines social and policy learning | Interviews and reviews of both regional and national policy documents demonstrate that in general, the implementation of centralized plans was not decentralized and did not involve social actors. The only exception found was Ghana's Self-Help Electrification Programme (SHEP). | Hypothesis validated |

Table 8.2 (Continued) Summary of Hypotheses, Evidence and Conclusions

| | | |
|---|---|---|
| **H3.** The low level of domestic ownership of the electricity sector negatively impacts the widespread implementation of regional plans. | Interviews and the peer-reviewed literature showed that the majority of the funding for ECOWAS projects is through large loans and International Competitive Bids (~85%), which overwhelmingly favor the policy of privatization and restructuring. give local companies only a small chance of competing. Furthermore, the debt burden usually lasts for decades. | Hypothesis validated |
| **H4.** The general condition of weak local technological capability promotes turnkey solutions to technological challenges. It undercuts the ability to build an innovation system around renewable energy. | Interviews with stakeholders and a review of policy documents demonstrated that while this general condition does exist, the lack of an innovation policy is the reason for the continuing dependence on turnkey solutions. | Hypothesis rejected |

## 8.4 Policy Implications

The overwhelming similarity of the characteristics of West African countries with respect to the problems of electricity provision that they face, justifies the need to pool together their resources to address their common challenges, as seen in the formation of organizations such as the West African Power Pool (WAPP), the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), and the ECOWAS Regional

Electricity Regulatory Authority (ERERA). Furthermore, these groupings provide an opportunity for countries to learn from each other's experiences and strategies and disseminate best practices as well as specific difficulties that they encounter. However, in the face of generally slow progress, and in some cases, decline in the consistency of supply and the rate of access to electricity services, there is a need to fundamentally reexamine the dominant policy and planning approaches to electrification in order to critically determine which alternative or complementary paths may be taken.

The findings that emerge from the research carried out in this dissertation project point to a number of policy implications both in the long term and in the short term. In the long term, it is important to adopt a planning philosophy or paradigm that explicitly takes into consideration the multiple goals and aspirations that a viable electricity sector can help to meet, in order to avoid reducing the problems to primarily technical and economic ones. An integrative framework such as that of adaptive management is one that can be used creatively to foster the interaction of science and technology with multiple values. In addition, it would enable the policymaker or analyst to view policies as carefully designed experiments to be learned from, and that build in flexibility and adaptive capacity, rather than solutions to given problems. Indeed, one of the findings from the U.S. case studies was that the disposition of those who participated in the AM programs toward flexible and collaborative decision making was a more important factor in the success of those programs than the rigor of the technical experimentation itself.

The need for a more democratic and participatory decision-making process highlighted cited above is another policy implication for West Africa with respect to electricity planning. However, while the AM programs in the U.S., particularly at the

Northwest Power and Conservation Council and at the Glen Canyon Dam resulted in decreases in hydroelectric power production as a tradeoff for the preservation of other values such as endangered species or recreation, a similarly desirable scenario in West Africa would still leave the issues of access and adequate generation unresolved. Nevertheless, this principle of maximum collaboration with stakeholders would need to be intensified in the region, with respect to a wider range of resources and to strategies for extending access to non-electrified areas.

In particular, Ghana's Self Help Electrification Programme (SHEP) invited communities to initiate their own electrification plans by purchasing a certain number of low voltage poles and supplying labor in exchange for the collaboration of the ministry of energy, the district assemblies, the local distribution company and network operator, as well as local construction contractors and foreign suppliers of equipment, in order to fast track the National Electrification Scheme (NES) in their own localities. These initiatives, which were independent of environmental management efforts associated with power production and separate from the reform efforts, increased the overall rate of access in Ghana from about 25% when they began, to over 60% today, and from 5% in rural areas to about 30% today.

Thus, an additional policy implication of the Ghanaian experience is that a combination of multiple instruments and schemes that are used to implement a nationally defined strategy is preferable to a single dominant scheme of electric sector reform and restructuring, which is an acontextual policy indiscriminately recommended to all countries in the region. The multi-pronged strategy adopted in Ghana, which was part of a centralized approach to electricity generation and transmission, allows room for policy learning and introduces a higher degree of adaptive capacity into the sector. This is in contrast to the dominant strategy adopted by most of the other countries, which is characterized by "technicisim" and "economism", that is, an overreliance on narrow technical and economic considerations, and in some cases, an excessive financial investment in these, such as in the case of Nigeria. Despite its relative success by regional standards, however, Ghana too, still faces electricity shortages in connected areas which will likely slow down the rate at which access is extended to non-electrified areas.

This leads to another implication which emerges from the analysis of non-West African countries that had rapid electrification programs, in particular, China and South Africa. These countries successfully implemented both institutional and technological innovation in their programs that were explicitly geared toward addressing the social function of electrification. Thus, the policy implication for West African countries is that while bold institutional reforms are necessary, they may not be sufficient in and of themselves to achieve near universal electrification unless the countries begin to marshal their financial and human resources to pursue technological innovation. Such a policy would be required for both centralized and decentralized energy generation technologies.

The potential for technological innovation to significantly improve electricity access and supply ties into the need for West African countries (and all countries) to transition to more sustainable economies that are primarily driven by energy efficiency and conservation, renewable resources, and combined heat and power (CHP) before other resources as required in the AM scheme for electric power management. Denmark and China provide good examples of how this can be done. This brings the policymaker or analyst full circle back to the application of adaptive management to the use of energy resources, where the order of priority outlined above has been established. When linked to the application of AM to ecological issues that are impacted by electricity generation, the policy implication for West Africa is that in order to achieve the high rates of electrification achieved in many other countries around the world, but do so in a more sustainable way, the region would have to adopt a comprehensive strategy at an early stage that includes not only social and economic considerations, but also integrates environmental concerns into the planning itself. The various analyses presented in this dissertation offer examples of how different aspects of this can be done.

Another policy implication that emerges from the various cases and countries is that a strong political will coupled with broad-based participation is a precondition for the widespread provision of electricity. In all of them, a strong decision was made, starting with a recognition of local conditions and challenges, to initiate a policy with broad-based participation and support, and modify it along the way until it became more effective. Thus, China decentralized the implementation of what was a centrally-written plan to promote the policy of "self-construction, self-management and self-use" at the regional level, Denmark also decentralized the implementation of a nationally-driven plan to pursue wind energy by including artisans and craftsmen in the innovation process, and following its transition to democracy, South Africa implemented its Free Basic Electricity Policy to ensure that households that could be connected to the grid would receive the minimum amount of electricity they needed free of charge. In West Africa, Ghana instituted its Self-help Electrification Programme within its national scheme and Cape Verde, a small island nation, is the regional leader in both access rates and renewable energy-based electrification, but few other countries have demonstrated the political will to extend electricity access throughout their countries.

The implication of this situation in the poorly electrified countries is that civil society organizations and communities will have to take the lead in initiating their own electrification plans, finding alternative and creative ways to fund these, and raising awareness and providing information about electrification options that are available at a local level. These groups could also build broad-based alliances across all sectors of the society and enlist the participation of sympathetic government officials until such a time as a sufficient confluence of factors occurs that can open up a policy window that could enable a closer alignment between the actions of the state and the interests of the majority of the people.

Thus, the efforts of civil society organizations initiating collaborative management activities in the Volta River Basin and in the Komadugu-Yobe Basin should be further supported, intensified and interlinked with one another. In particular, the Songhaï Centre offers a practical model for embedding social, ecological and economic factors, including technological innovation, into electricity planning and sustainable development more generally. It also bases its activities on a guiding philosophy that is grounded in the realities of the region, as well as some of the best values of the continent as a whole. Ultimately, if these types of initiatives and stakeholders are more directly involved in regional planning rather than the supranational organizations merely being made up of representatives of the various states, then policy diffusion and capability building strategies may be disseminated much faster.

### 8.5 Limitations and Future Work

One of the limitations of this work was that because being able to travel to more West African countries was cost-prohibitive, in-depth interviews in fewer countries than would have been ideal were carried out. Another limitation was that surveys and questionnaires were not administered to electricity users to gain more insight into their technology and policy preferences as well as their willingness to pay for certain services.

Two broad directions for continuing this work are envisaged in the future. One is pursuing the research on systems of innovation for a transition to sustainability in both a comparative cross-country or cross-regional perspective, and in a multi-level perspective on socio-technical systems. Another line of research would be a deeper analysis of Traditional Ecological Knowledge (TEK) and its relationship to adaptive management in an effort to identify the points of compatibility and difference in applying AM in rural communities as well as better informing AM in urban settings with insights from TEK.

Finally, the totality of the findings in this dissertation offers a topical and geographical contribution to support the view that contextual understanding, analytical rigor, and scientific knowledge are neither mutually exclusive categories, nor are they antithetical to one another, but that rather, their judicious use and integration can significantly increase the likelihood of attaining more sustainable and democratically achieved outcomes. Thus, notwithstanding the limitations of the study, which are the author’s alone, and the future work that remains to be done, they further support the notion that the march toward a more sustainable future does not depend on finding “correct” solutions to complex problems, as much as it does on seeking to continually improve on collective learning processes and management practices.

# APPENDICES

## APPENDIX A: List of Interviews Conducted

| Organization | Position | Location | Date |
|---|---|---|---|
| Songhai Center | Director | Porto-Novo, Benin | 12/4/2010 |
| Exxon-Mobil | Geophysicist | Lagos, Nigeria | 12/14/2010 |
| WAPP | Head, Admin/Finance | Cotonou, Benin | 12/20/2010 |
| WAPP | Head, Studies and Planning | Cotonou, Benin | 12/29/2010 |
| WAPP | Director, Planing, Investment Programming and Environmental Safeguards | Cotonou, Benin | 12/29/2010 |
| KNUST | Director, Consultancy Centre | Accra, Ghana | 1/4/2011 |
| National Dialogue on Dams, Ghana | General Secretary | Accra, Ghana | 03/05/2012 |
| KYB Project, Nigeria | Chairman of the Joint Stakeholders Consultative Network of the Komadugu-Yobe Basin (KYB) | Kano, Nigeria | 03/20/2012 |
| ECREEE | Renewable Energy Expert | Praia, Cape Verde | 03/10/2012 |
| Glen Canyon Adaptive Management Program (GDCAMP) | Retired Lower Colorado River Coordinator for the U.S. Fish and Wildlife Service and Designated Representative of the GDCAMP Work Group | Phoenix, Arizona, U.S.A. | 05/08/2012 |
| Northwest Power and Conservation Council (NPCC) | General Counsel | Portland, Oregon, U.S.A. | 06/05/2012 |

**APPENDIX A (Continued):** List of Interviews Conducted

| | | | |
|---|---|---|---|
| Northwest Power and Conservation Council (NPCC) | Senior Power Systems Analyst | Portland, Oregon, U.S.A. | 06/07/2012 |
| Tennessee Valley Authority (TVA) | Adviser to Senior Vice-President of the office of Environment and Research and Integrated Resource Plan (IRP) Project Manager | Knoxville, Tennessee, U.SA. | 07/16/2012 |
| Tennessee Valley Authority (TVA) | Aquatic Ecologist, Threatened and Endangered Species | Knoxville, Tennessee, U.SA. | 07/16/2012 |
| Tennessee Valley Authority (TVA) | Specialist, Aquatic Species Endangered Act Permitting and Compliance, and Manager of Technical Staff | Knoxville, Tennessee, U.SA. | 07/16/2012 |
| Tennessee Valley Authority (TVA) | National Environmental Policy Act (NEPA) Project Manager, historian, IRP Manager | Knoxville, Tennessee, U.SA. | 07/16/2012 |

**APPENDIX B: Maps of Adaptive Management Sites in the U.S.**

APPENDIX B1: Columbia River Basin

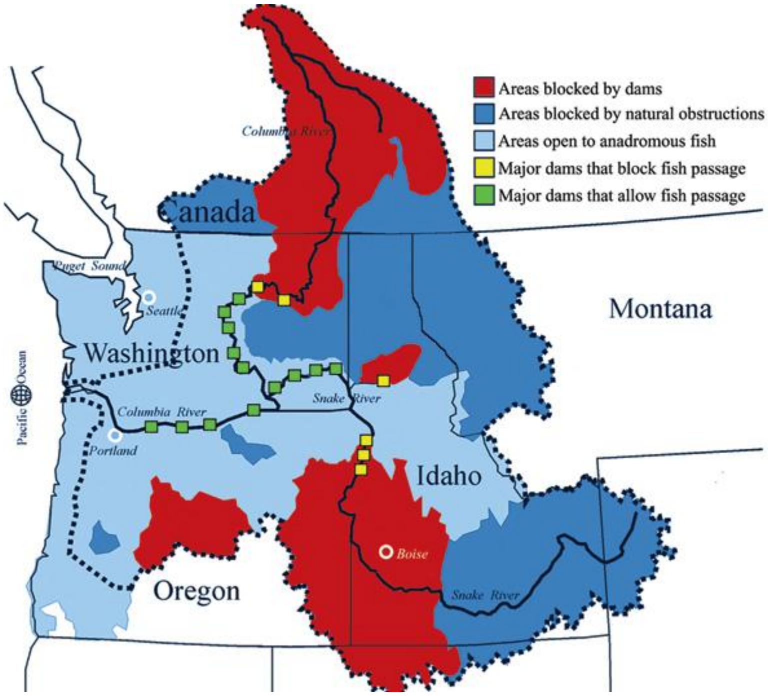


Figure B1. Map of the Columbia River Basin (NPCC 2010)

APPENDIX B2: The Tennessee Valley

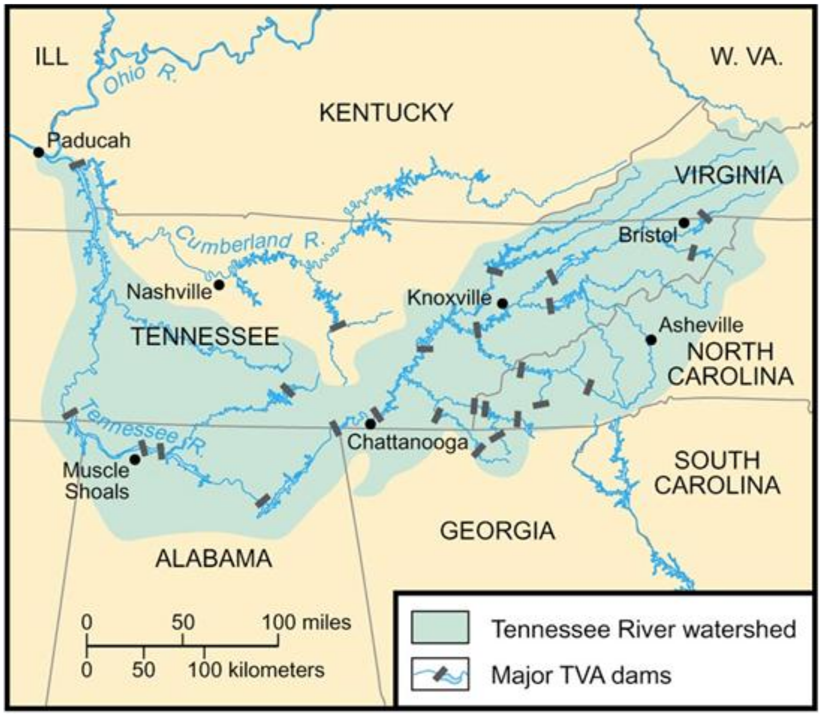


Figure B2. Map of the Tennessee Valley (Jones 2004)

APPENDIX B3: Glen Canyon Dam

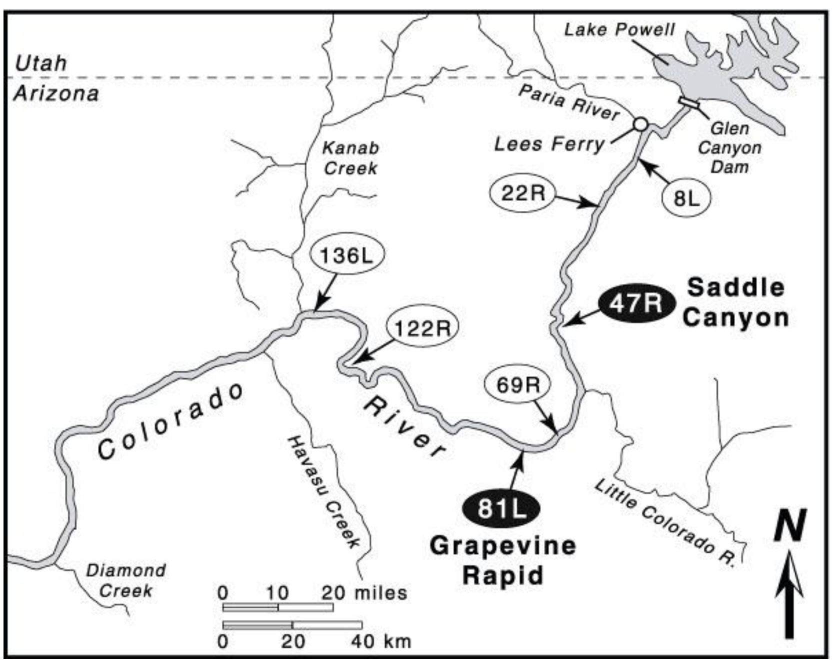


Figure B3: Map of the Glen Canyon Dam (Barnhardt, Kayen et al. 2001)

# APPENDIX C: Maps of Prospective Adaptive Management Sites in West Africa

APPENDIX C1: Volta River Basin


Figure C1: Map of the Volta River Basin (GLOWA 2010)

APPENDIX C2: Komadugu-Yobe Basin

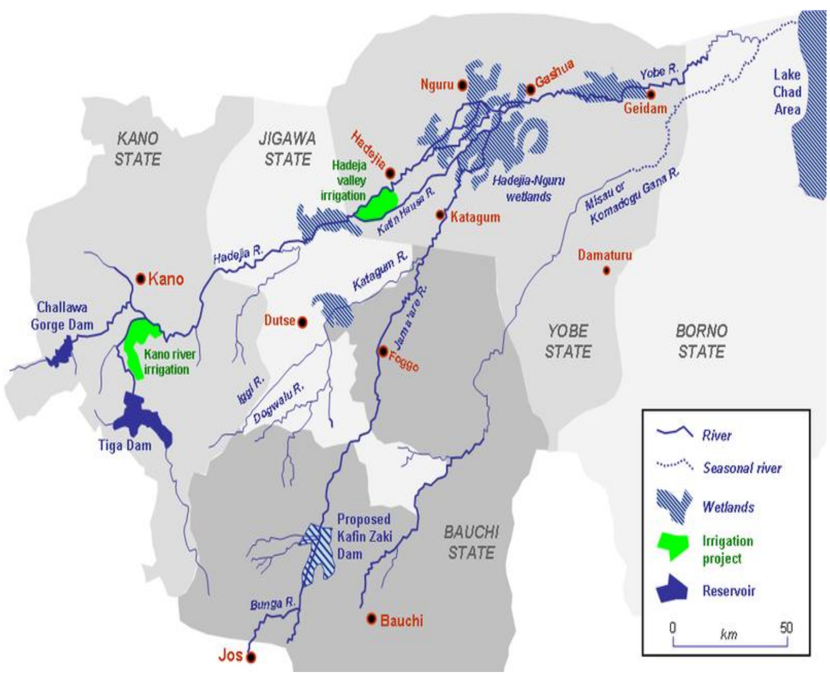


Figure C2: Map of the Komadugu-Yobe Basin

## APPENDIX D: SOLAR AND WIND ENERGY POTENTIAL IN WEST AFRICA

**APPENDIX D1:** Estimated Solar Energy Generation

| | Land Area ($km^2$) | Land Area ($m^2$) | Average Solar Radiation ($kWh/m^2day$) | Energy (PWh) |
|---|---|---|---|---|
| | | | | E=Land area*solar radiation |
| Benin | 110,620 | $1.10 * 10^{11}$ | 5.23 | 31.6 |
| Burkina Faso | 273,600 | $2.74 * 10^{11}$ | 5.94 | 89.0 |
| Cape Verde | 4,030 | $4.03 * 10^{9}$ | 6.60 | 1.5 |
| Côte d'Ivoire | 318,000 | $3.18 * 10^{11}$ | 4.90 | 85.4 |
| Gambia | 10,000 | $1.00 * 10^{10}$ | 6.24 | 3.4 |
| Ghana | 227,540 | $2.28 * 10^{11}$ | 5.24 | 65.3 |
| Guinea | 245,720 | $2.46 * 10^{11}$ | 5.87 | 79.0 |
| Guinea Bissau | 28,120 | $2.81 * 10^{10}$ | 5.67 | 8.7 |
| Liberia | 96,320 | $9.63 * 10^{10}$ | 5.15 | 27.1 |
| Mali | 1,220,190 | $1.22 * 10^{12}$ | 6.48 | 432.7 |
| Niger | 1,266,700 | $1.27 * 10^{12}$ | 6.35 | 440.1 |
| Nigeria | 910,770 | $9.10 * 10^{11}$ | 5.25 | 261.8 |
| Senegal | 192,530 | $1.93 * 10^{11}$ | 6.37 | 67.1 |
| Sierra Leone | 71,620 | $7.16 * 10^{10}$ | 5.65 | 22.1 |
| Togo | 54,390 | $5.43 * 10^{10}$ | 4.84 | 14.4 |
| ECOWAS | 5,030,150 | $5.03 * 10^{12}$ | 5.718 | 1,629.4 |

Note: The land area used here is the total area of a country, but that excludes the area under inland water bodies, any claims to an adjoining continental shelf, and exclusive economic zones outside the territorial limits. This is justified in the analysis presented in this chapter because of its emphasis on solar home systems (SHSs).

**APPENDIX D2: Estimated Wind Energy Generation**

| | Land Area ($km^2$) | Average Wind Speed at 10 m ($m^2$) | Average Wind Speed at 50 m ($m^2$) | Energy (PWh) at 10 m | Energy (PWh) at 50 m |
|---|---|---|---|---|---|
| Benin | $1.10 * 10^{11}$ | 2.65 | 3.35 | 29.1 | 295.3 |
| Burkina Faso | $2.74 * 10^{11}$ | 2.52 | 3.19 | 62.1 | 630 |
| Cape Verde | $4.03 * 10^{9}$ | 4.44 | 5.62 | 5.0 | 50.7 |
| Côte d'Ivoire | $3.18 * 10^{11}$ | 2.58 | 3.12 | 77.3 | 685.6 |
| Gambia | $1.00 * 10^{10}$ | 4.17 | 5.28 | 10.3 | 104.3 |
| Ghana | $2.28 * 10^{11}$ | 2.97 | 3.58 | 84.3 | 740.9 |
| Guinea | $2.46 * 10^{11}$ | 3.56 | 4.51 | 157.1 | 1,592.0 |
| Guinea Bissau | $2.81 * 10^{10}$ | 4.57 | 4.58 | 38.2 | 191.0 |
| Liberia | $9.63 * 10^{10}$ | 2.49 | 3.16 | 21.2 | 214.6 |
| Mali | $1.22 * 10^{12}$ | 4.39 | 5.56 | 1,466.2 | 14,877.0 |
| Niger | $1.27 * 10^{12}$ | 3.43 | 4.34 | 721.9 | 7,315.6 |
| Nigeria | $9.10 * 10^{11}$ | 3.72 | 4.53 | 662.9 | 5,998.5 |
| Senegal | $1.93 * 10^{11}$ | 4.41 | 5.58 | 233.7 | 2,369.6 |
| Sierra Leone | $7.16 * 10^{10}$ | 3.38 | 4.28 | 39.2 | 397.0 |
| Togo | $5.43 * 10^{10}$ | 2.98 | 3.77 | 20.3 | 205.6 |
| ECOWAS | $5.03 * 10^{12}$ | 3.48 | 4.30 | 3,629 | 35,668 |

Note: The land area used here is the total area of a country, but that excludes the area under inland water bodies, any claims to an adjoining continental shelf, and exclusive economic zones outside the territorial limits. This is justified in the analysis presented in this section because of its emphasis on wind turbines for household use and not off-shore wind generation.

## APPENDIX E: Sample Interview Questions

APPENDIX E1: Columbia River Basin

Northwest Power and Conservation Council (NPCC) Interview 1:

1. Can you please tell me what your position with the Northwest Power and Conservation Council is and what you do in that capacity?
2. What is the primary guiding government document or policy for power planning in the Pacific Northwest? Is it still the 1980 Pacific Northwest Electric Power Planning and Conservation Act? Is it the Council's $6^{th}$ Power Plan? Or both?
3. What is the nature and extent of community participation in energy planning? That is to say, apart from utilities and other interest groups?
4. What is the proportion of quantitative modelling and qualitative management within the AM process? How is the balance struck? In other words, I am asking about how the science-management integration process, or the "compass and gyroscope" interaction, from your experience as Counsel.
5. Could you please tell me about some of the successes and current challenges of the Northwest Pacific Power Council (NPPC) from your perspective?
6. Outside of the Northwest Power and Conservation Council of the Columbia River Basin and the Glen Canyon Dam Adaptive Management Program (GCDAMP), are you familiar with any other systems that involve power generation and that use AM? And perhaps even with coal, nuclear or renewable power generation? I am aware of the everglades program but this does not involve any electric power. If so, do you interact with or learn from these other programs?
7. In 1996, Professor Kai Lee, a prominent adaptive management scholar published an article where he appraised AM as an approach to policy implementation, and argued that it had been more influential as an idea than in practice because a "collaborative structure" has to be put in place first (partly because ecological time responses are long, and partly because the battle for control of ecosystems has not been decided in a lot of places). In particular, he argued that the experimental phase of the AM efforts initiated by the NPPC did not go very far because those efforts were diverted by litigation under the 1990 Endangered Species Act. Sixteen years later, how would you respond to this evaluation?
8. Also, according to (Lee 1999), the only successful AM project in history was the one started in 1988 by Prof. Keith Sainsbury in South Australia, where they were able to educate fishermen in science and thereby quadruple the amount of fish they caught from a declining groundfish fishery, a process which took about 10 years to yield practical results. Do you know of any other ones?
9. Lastly, in an international perspective, Adaptive Management would appear to face additional challenges in implementation in countries where there is no strong governmental authority that can enforce regulations and control access to the resources being managed. What can you tell me about the feasibility of AM in these contexts, either from your work abroad or from interactions with international visitors?

Northwest Power and Conservation Council (NPCC) Interview 2:

1. Can you please tell me what your position with the Northwest Power and Conservation Council is and what you do in that capacity?

2. What is the general heuristic that guides your approach to power planning? Is it based on or similar to the simplified one laid out by Professor Kai Lee in his essay "The Path Along the Ridge: Regional Planning in the Face of Uncertainty"?
3. What is the nature and extent of public participation in energy planning? In other words, how do you consider or incorporate the interests and concerns of utilities and interest groups such as large industrial consumers into your work? What about the larger public?
4. How do you coordinate your planning activities with that of the utilities or the Bonneville Power Administration, for instance? Whose work takes higher precedence?
5. Could you please tell me about some of the successes and current challenges of the current approach to power planning in the face of uncertainty?
6. Outside of the Northwest Power and Conservation Council, are you familiar with any other systems that apply AM concepts to power planning?
7. What are some of the similarities between your approach and the scenario planning approach used in some integrated resource plans (IRP) such as that of the Tennessee Valley Authority?
8. What role do power pooling arrangements within the Pacific Northwest play in your work?
9. From your perspective, what are some of the barriers to introducing distributed renewable energy resources, which are often dispersed and intermittent into the grid with respect to standardization and monitoring? How is this different for utilities versus individual household producers of energy?

APPENDIX E2: Volta River Basin

National Dams Dialogues Interview:

1. Can you please tell me what your current position is as a person who works on dams and development, and what you do in that capacity?
2. What is the primary guiding government document or policy for dam management in Ghana?
3. Is there a requirement, and to what extent does this document require community participation in local energy planning?
4. You have participated in the National Dialogues on Dams and Development in Ghana. What was your role within the National Coordinating Committee?
5. Could you please tell me about some of the successes and failures of the NCC?
6. My understanding is that the two main dams in Ghana are the larger one at Akossombo and a smaller one at Kpong. What are some of the similarities and differences in the way both are managed?
7. What is the nature of the relationship between those energy or environmental professionals whose training is based on Western science and members of the community who are trained in Traditional Knowledge with respect to the management of the river basin?

8. What are the possibilities of incorporating local knowledge, materials, ideas and values into the management of dams in Ghana in a holistic way?
9. What is the nature and extent of Ghana's coordination with ECOWAS or some of its agencies such as the West African Power Pool (WAPP) or the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE)? And what is the extent of Ghana's collaboration with other West African countries with respect to their work on dam management?
10. Are you familiar with the concept of "Adaptive Management" as an approach to ecosystem management? If so, is this approach explicitly used or mentioned in Volta River Basin management? And if so, for how long?

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