Powering Accra: Projecting Electricity Demand for Ghana’s Capital City

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Abstract:

The purpose of this research was to create an agent-based urban simulation based on land use at the plot level for projecting the disaggregated electricity demand of the Greater Accra Metropolitan Area (GAMA). A simulation system comprised of location choice, regression, and simple models were used to project household, employment and land development decisions. Households, persons, and jobs tables were synthetically generated from GLSS5 (Ghana Living Standards Survey 2005) data using Stata, built in a MySQL database and incorporated for use in the Open Platform for Urban Simulation (OPUS). Electricity demand was projected for each of the simulation years based on a regression model. Numerous geospatial datasets were projected and edited in ArcGIS which describe the physical composition of Accra in its totality, including buildings, roads and electricity infrastructure. Household mobility was estimated from a modified Cox Regression of residential mobility in Accra (Bertrand et al.) and applied to the GLSS5 for use in the location choice model, while employment coefficients and parameters describing land value were derived from literature (Buckley et al.). The model has been applied for projecting the electricity demand of the Korle Bu district in terms of high, medium and low economic and population growth rates for the time period 2006 until 2025, based on monthly electricity consumption per meter. An additional phase of this research envisions including all 12 GAMA districts (using data which has been obtained); infrastructure models to project demand for transportation, water & sewer, and solid waste facilities; as well as comparing weak and strong sustainability scenarios with the business-as-usual development path for cost-benefit analysis of proposed public policies.
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Chapter 1

Urban Studies and Electricity Use Planning in the Developing World
1.1 Development Research and the City

Sir Hans Wolfgang Singer first identified one of the fundamental tenets of development research when he identified that the terms of trade between primary products and manufactured goods tend to deteriorate over time. The Singer thesis states, when resource flows from a periphery of poor and underdeveloped states to a core of wealthy states, the later will be enriched at the expense of the former. This occurs because as incomes rise, the demand for manufactured goods increases more rapidly than demand for primary products, and thus implying that it is the very structure of the market which is responsible for the existence of inequality in the world system. From this thesis emerged the concept that wealthy nations have a certain moral obligation to assist with the development of poorer nations, such that poverty is reduced, self-sufficiency is promoted, and in the future, an industrialized economy will develop. It is this idea that has served as the basis for United Nations and World Bank programs, such as the International Development Association, the United Nations Development Program, and the World Food Program. It is also one of the fundamental tenets of the Zentrum fur Entwicklungsforshung (ZEF) as well as the Globaler Wandel des Wasserkreislaufes (GLOWA), the institute and project hosting this doctoral work. (Singer, 1950)

In the post World War II era, development research has generally focused on poverty reduction, predominantly in the more rural, agricultural parts of developing countries, since impoverished households have been predominantly located within rural areas. Agricultural economists, hydrologic engineers, and social scientists have served to improve the lives of thousands of poor, rural households through managing water use for equitable allocation, promoting best management practices for agricultural and forest land uses, developing a better understanding of the causes of child mortality, as well as focusing on issues global phenomenon such as the dynamics of rural to urban migration and the impact HIV-AIDS, malaria, and famine have had on the Sub-Saharan. While these issues have not diminished in their importance, over the past 10 years a new, dramatic trend has begun to emerge across the landscape of the Sub-Saharan. Urbanization is reshaping the face of Africa and is demanding that urban and regional planning be incorporated as an integral part of the development research agenda.

1.1.1 Africa’s Urbanization

The urbanization of Sub-Saharan Africa is occurring more rapidly than in any other region in the world, at a historically unprecedented absolute rate of increase. The current growth rate of almost 5 percent per year implies close to a doubling of the urban population in 15 years, with new urban residents projected to rise sharply by over 300 million between 2000 and 2030, more than twice the rural population increment (Figure 1). This implies that much of the new demand for jobs and services, as well as the supply of human energy to meet the countries’ future needs, will appear in urban areas. (Kessides, 2006)

The demographic picture of Africa is one of change with the urban demographic growth coming from three sources: natural increase among existing urban residents, reclassification of formerly rural areas as urban, and internal rural-urban migration. The underlying dynamic of high urban growth rates are predominantly driven by natural increase, due to persistently high fertility rates and slowly declining mortality. Suburban land use reclassification and migration, together account for less than half (about 40%) of urban growth estimates. Furthermore, it is also necessary to explain rural-to-urban migration by “pull” factors, economic opportunities that attract residents to a city, and “push” factors, the lack of opportunities in rural areas. It is also significant to note that the traditional view of one-way rural-to-urban migration is much less important in overall population mobility than circular and seasonal migrations. And finally, perhaps the most important point regarding Africa’s rapid and dramatic demographic change is that the real surge in urbanization is yet to come, with most of this growth...
Across all countries over time, the level of urbanization is strongly correlated to the level of economic development. In Sub-Saharan Africa this correlation is evident when comparing the levels of urbanization and of constant GDP per capita over the last decade (1990 to 2003), and is important to recognize because the economic growth that has taken place in recent years is on the whole mainly urban based. The industrial and services sectors, which roughly approximate urban based activities, accounted for at least 60 percent, and averaged almost 80 percent, of GDP growth in the region between 1990 and 2003. Additionally, the informal economy which cuts across all sectors and is predominantly urban based, has been estimated to contribute as much as 1/3rd of the total GDP in some African nations (Cameroon). Furthermore, the informal economy workforce is estimated to account for 78 percent of nonagricultural employment, 93 percent of all new jobs created and 61 percent of urban employment. Despite the strong performance of the urban based sector, for most of Africa the growth of total GDP in per capita terms has been insufficient to turn around poverty (Figure 2). If Sub-Saharan Africa is to meet the MDG of reducing poverty to 22 percent by 2015, the real GDP of African countries will need to grow by at least 6 percent per year (or slightly less if inequality improves). Policies that promote economic development through improved city planning and capital improvements will be required to enable the growth necessary in the industrial and services sectors to meet these MDG goals. (Baker, 2008)

An almost universal finding in developing countries is that rural poverty rates exceed urban poverty rates often by a very large margin, but in Sub-Saharan Africa figures show the difference between rural and urban poverty rates are actually quite close, and this gap is projected to close. Assuming no change in rural and urban poverty incidence, in twenty years half or more of the poor would reside in urban centers. Also, assessing the nature of urban poverty requires looking beyond monetary measures. Often the urban poor suffer from food insufficiency due to affordability, and while the location affords proximity to social
and infrastructure services it does not guarantee actual access or affordability. Physical infrastructures such as electricity, water and sewer, and transportation improvement are often extended to more remote and scattered but better-off neighborhoods while neighborhoods where the urban non-poor, which are more often even adjacent to existing infrastructures, are ignored. It’s also difficult to quantify non-monetary costs for activities such as obtaining water or using sanitary facilities which may be in direct physically proximity to a household, but difficult to access due to the sheer numbers of people depending on them. Consequently, the UN-Habitat estimates that over 70 percent of the urban population suffers shelter deprivation in terms of inadequate housing, water supply, or sanitation helps to explain why the MDG target of reducing infant mortality is projected to not be met in the urban areas of most African counties. Such instances of inequitable infrastructure and social service planning are evidence that much of the deprivation in cities relates to institutional failures that perpetuate social exclusion between the urban poor and urban non-poor. Correcting intra-urban inequalities is good value since the urban slums and peri-urban residents form the core or the urban workforce and it is cost effective to ensure their effective access to basic services. (Kessides, 2006)

Cities financial performance, and therefore also their performance in service delivery, depends in the first instance on the intergovernmental fiscal framework that determines their authority to tax and their access to various forms of central revenues. While in the European Community local public expenditure averages 11 percent of GDP, in only a few African countries it amounts to 5% of GDP, and much more often is closer to 1%. The tax and borrowing authority for the cities, especially large cities and localities facing rapid population growth, rely less on taxation and more on transfers, and they are typically not

Figure 1.2 Real Per Capita Income in Sub-Saharan Africa has not Improved (GDF & WDI, 2004)
adapted to their greater expenditure and service delivery obligations. Local administrations have weak fiscal and administrative means, and are barely up to the task of maintaining services, let alone meeting the demands of growth. The result is public services are almost non-existent outside the wealthy neighborhoods and in many African cities firms and households subsist by their own grit. (Kwapong, 2008)

1.1.2 Urban Planning and African Cities

Good urban management feeds into the entire national growth and welfare agenda, stimulating agricultural intensification and diversification of rural income, poverty reduction, good governance, and fiscal resource mobilization. Options for intensified agriculture and diversification into nonfarm production prove to be complimentary; they can also be fostered by common conditions, especially by effective access to major urban markets. The most constructive way of looking at the productive interlinkages among urban and rural areas may be as a virtuous circle, whereby access to urban markets and services for nonfarm production stimulates agricultural productivity and rural incomes, which in turn generate demand and labor supply for more such goods and services. (Kessides, 2006)

Urban areas epitomize the process of endogenous growth, whereby resources are used more productively and in new ways. Releasing the potential of Africa’s cities by addressing basic weaknesses in land markets, public transport, and the provision of urban services could reduce an effective “binding constraint” to future growth in Africa. These benefits do not arise from the mere physical concentration of people and firms but from the ability of cities, and in particular their governments, to create an environment in which economic agents can easily interact, labor is mobile, urban land can become available for productive uses, and both citizens and firms trust they can safely invest in the future. Failure to ensure these ingredients of leads to ineffective cities and very high opportunity costs, both by lowering returns to urban assets and by provoking negative outcomes such as environmental degradation and social distress. (Mabogunje, 2005)

There are many advantages to meeting poverty reduction in urban areas. For example, the per capita costs of many forms of infrastructure and social services are generally lower, as many more people can be reached. Additional benefits can be a result of access to income from nonfarm and urban-based activities is associated with reduced rural poverty, and options for such income multiply in proximity to urban markets. Remittances represent such an important supplement to household incomes, not only from abroad, but also from the city to rural areas. Interestingly, remittances are likely to exceed microcredit or development assistance as a supplemental resource for many households. Also, improved transportation which enable migration or mobility is clearly a favorable element in income growth and poverty reduction, for both urban and rural populations. Policies should enable labor mobility as an element of general welfare and poverty reduction strategies. At the same time, migration can pose major challenges to the receiving areas by adding to near-term demands for services, raising the stakes for good urban management. (Baker, 2008)

African cities need to improve their basic flexibility of the markets, including reducing barriers for workers to obtain jobs, improving residential mobility and decreasing limitations on land use. There is large demand to make local public services more efficient, both those that can be produced through public-private partnerships and those that are pure local public goods. Also, by improving trust and confidence in government, the private sector and households won’t be deterred from investing and partnering for the future, which alleviates some of the burdens borne by the public sector. Much greater benefits could be mobilized for the country and for urban inhabitants by focusing on basic investment and on efficient functioning of the essential core of land and housing, environmental services, public transportation, and
In Africa, the housing sector is overwhelmingly informal, but with the right policies and institutions it could become a powerful engine for growth of jobs and for deepening the financial system. And while African governments dominate the ownership and use of urban lands, they fail to protect rights-of-way or to prevent sensitive areas from being settled. Poor regulation leads to low density, urban sprawl, which further increases the cost of public services. The health and well-being especially of the poor, but also the middle class are put at risk from the lack of and poor quality of urban environmental public goods and services, most notably water and sanitation, solid waste disposal, drainage and preservation of green space. Failures in urban transport policy seriously compromise the movement of individuals as well as the circulation of goods, again shuttering the urban marketplace. Road traffic is barely managed and roads are highly unsafe for cars and pedestrians.

1.1.3 The Cost of Neglect
The failure to satisfy the basic conditions for effective cities will, in simplest terms, dilute the benefits that could be gained for the country. Neglecting African cities makes both firms and households more vulnerable to the diseconomies of urban agglomeration, which are observed in terms of: high costs of land; congestion and inadequate mobility; a polluted environment; and many other threats to social order, public health and public safety. Such risks are never entirely unavoidable within population concentrations, but they become greater and are prematurely imposed by very inadequate urban management. It is not credible to argue that diseconomies are outweighing the positive benefits of African cities, when these cities have virtually no working public transport or safe waste disposal, much of the land is held in public control with little available to meet market demand or the requirements that advance the public good, and infant mortality is rising due to poor public sanitation in the neighborhoods where most people live and work. (Kessides, 2006)

Unreliable infrastructure and high transaction costs undermine firms domestically, and this comparative disadvantage can be fatal for exporting firms attempting to participate in global markets. Urban poor children are found to be less healthy than their rural counterparts. Children in slums of Nairobi face enormously higher risks than do their peers living elsewhere in the same cities or rural settlements. The Ghana Statistical Service found that worsening indicators for urban poor, including underweight status, as relative to the rural poor.

Political preference is often given to reducing the relative dominance of the largest (primate) city and to promoting distribution or urban population and economic activity across a number of geographically dispersed, smaller cities. This approach inhibits optimal growth since large cities tend to be the most productive and the most attractive to innovative and information intensive economic activities. Urban policy should establish conditions and incentives that help existing local governments to mobilize revenues and to respond to the evolving demands for effective public services. Municipal development should be at the center of urban policy. Municipal management requires that local investment be on-budget and part of an expenditure plan, rather than undertaken through ad-hoc assistance arrangements. (Kessides, 2006)

1.2 Electricity Use and African Cities
The International Energy Agency (IEA) predicts that worldwide energy consumption in the year 2030 will be about 60% higher than it was in 2002. Approximately 85% of the future power supply will still be based on fossil fuels, the burning of which represents the most important driving force for climate change. Cities are important arenas for energy use and production, and while urban areas occupy only 2% of the earth’s
land surface, they are responsible for three-quarters of global energy consumption as well as approximately 85% of the global production of greenhouse gases. By 2030, 4.9 billion people, or 60% of the world’s population, will inhabit cities, and the people living in these cities will consume 73% of the world’s energy. In 20 years, cities will emit 73% of the world’s greenhouse gases. (NKGCF 2008)

Cities in the developing world are a particular concern, because 81% of urban energy growth will come from developing countries with their urban built up areas tripling in size. Developing countries will surpass OECD countries as the largest contributors of green house gas (GHGs) emissions by 2012, with their urban energy sectors being the primary force responsible for this dramatic increase. Within the urban energy sectors of developing countries, buildings and industries as well as energy supply and transportation present the highest potential for GHG reduction. (ESMAP 2009; The World Bank 2008; ESMAP 2007)

Cities offer strategic starting points for energy efficiency and climate protection. On the one hand, the concentration of people, material flows and residential districts makes it possible to reduce the consumption of resources because modern governance, planning and service concepts mean that more people can be supplied more economically using the same amount of transport, energy and space. Such gains in efficiency can flow into the surrounding suburban and rural areas, as well as into the national economy, to which large cities are integrated by means of resource flows and supply corridors. Also, the functional integration of urban industries, infrastructures and networks make the accelerated dissemination of innovations possible, not at least in the energy sector. An integrated approach to urban development is required which takes into account the overlapping fields of responsibility such as buildings, transportation networks, energy technologies, and citizen behavior, and integrates these into a long range planning approach.

### 1.2.1 Electricity Use and Poverty Reduction

Numerous studies have been conducted recently to determine the causalities between electricity consumption and gross domestic product or average annual income in developing countries. Narayan and
Smith examined the causal relationship between electricity consumption and gross domestic product in a number of Middle East countries, finding that a 1 percent increase in electricity consumption increases GDP by 0.04%. Chen, Kuo, and Chen conducted a similar study investigating the relationship between GDP and electricity consumption in 10 developing countries in Asia and likewise found that sufficiently large supply of electricity can ensure a higher level of economic growth. Lee conducted a study of developing countries and found long-run and short-run causalities from energy consumption to GDP, while Akinlo conducted a similar study in Sub-Saharan Africa and likewise found that energy consumption has a significant positive long run impact on economic growth in Ghana, Gambia, and Senegal among other African countries. (Narayan & Smith 2009; Chen, Kuo, & Chen 2007; Lee 2005; Akinlo 2008)

While these studies clearly state the positive causality between electricity consumption, GDP, and average annual income, in more practical terms, the availability of electricity in urban areas is part of an enabling environment that promotes economic development and quality of life. The availability of electricity is not a panacea to cure all the ills of poverty, but availability of modern electricity services will make commercial businesses more profitable, residential households more enjoyable, industries more productive, and institutions more effective. Furthermore, electricity supply is part of a virtuous cycle that not only supports increases in the average annual incomes, but is also important in transportation networks for traffic control and street lighting, in water and sewer networks for maintaining pressure and preventing backflows, as well as with hospital, schools, and public safety.

1.2.2 Urban Planning and Electricity Demand

Energy demand forecasting is an essential component of energy planning and formulating strategies and recommending policies. The task is not only developing countries where necessary data, appropriate models and required institutions are lacking, but also in industrialized countries in which these limitations are somewhat less serious. Most demand modeling focuses on econometric, end use, or hybrid approaches. The econometric approach establishes a relationship between the dependent variable and certain chosen independent variables by statistical analysis for historical data. The relationship so determined can then be used for forecasting simply by considering changes in the independent variables.
and determining their effect on the dependent variable. The discrete choice method and multinomial-logit model represent recent break-throughs in this type of approach. The end-use approach is more of a bottom-up approach which disaggregates energy demand in accordance with the individual land use (industrial, commercial, institutional, residential, transportation) and projects energy demand in accordance with those available, disaggregated end-uses and then summarizes the total derived demand. (Bhattacharyya, 2009)

1.3 The Remarkable Growth of Ghana’s Capital City

Global experiences illustrate that as economies grow, rapid urbanization takes place that encompass a large share of a nation’s population. In step with its Sub-Saharan location, Ghana is also experiencing unprecedented urbanization with approximately 50 percent of its more than 20 million people currently living in urban areas with this share expected to be 65% by 2030. The most significant growth is taking place in Accra, which is Ghana’s administrative and commercial center, as well as its largest and fastest growing urban concentration. Inhabited by more than 3 million people, representing 15 percent of the total population and 40% of the total urban population, Accra’s growth rate of 4% per year implies that the population will double in 16 years. But these projected increases are not a new trend, instead they are an extension of the past 15 years when Accra also doubled its population and expanded its area almost three fold. Between 1990 and 2005 the built up area increased from 133 square kilometers to 344 square kilometers, and the population density decreased from 14,000 persons per square kilometer to 8,000. (United Nations, 2005; World Bank, 2007; World Bank, 2009)

The urbanization pattern of Accra reveals strong physical growth, which is typified by moderate and patchy densification within the inner core, involving the replacement of residential by commercial uses, and uncontrolled and low density peripheral growth. This urban sprawl is expanding the boundaries of Accra and a key issue that emerges is the efficient delivery of infrastructure and services. Lack of comprehensive urban development policies and inadequate implementation of programs on urban management, land use, transport and economic development is permitting unbridled urban sprawl, which not only limits the growth potential of all sectors but also has a particularly significant affect on the most vulnerable sections of society due to their dependence on public systems. (World Bank 2007; World Bank 2008; Mabogunje, 2005)

![Figure 1.5 Ghana Urban and Rural Population Growth (UN – World Urbanization Prospects, 2005)](image-url)
Without a clear policy direction and vision, the ability of cities to grow competitively and remain bankable and livable is often compromised. Like most Sub-Saharan countries, the growth of the agriculture sector in Ghana is slowing down and “push factors” are causing migration to towns and cities. However, the urban areas are not generating enough economic growth for the increased population and local authorities do not have sufficient resources or expertise to make comprehensive provisions for public services, such as electricity, water, transportation, education, health care, and public safety. While a contraction of the agricultural sector has served to encourage rural to urban migration, natural increases due to high fertility and greatly reduced child mortality rates in urban areas as well as the reclassification of rural areas to urban lands are the primary explanations for the growth of Ghanaian cities.

There is a strong need for Government commitment to address the emerging issues of the urban sector. It is clear that urbanization is here to stay and that it needs to be tackled strategically within the context of economic development and poverty reduction. There is a pervasive inertia which has prevented the Government of Ghana from effectively and decisively tackling the decentralization agenda and the subsequent service delivery and financing of local investments. Ghana needs to move away from “business as usual” and move towards sustainable solutions that link municipal management reforms to improved access to services and economic growth, providing operational tools for future planning, improving transfers and local taxation and creating an environment favorable to business and economic activities. (The World Bank, 2008)

Land management remains a key constraint for effective growth in Greater Accra. The dual system of land delivery, traditional and public, and the lack of systematic planning at the local level have created a complicated system of property rights. Existing revenue mechanisms like property tax rates add minimal value to the local government own-source revenues. Furthermore, the poor have very limited access to decent shelter and are often forced to live in slums or overcrowded tenements. The rapid demand for

Figure 1.6 Urban Sprawl of Accra, Ghana from 1985 until 2000 (Buckley, 2005)
land in Accra has significantly increased land values in the central business districts, so that they are now comparable to some European Cities. But, lack of property rights is having an impact on business development, and within the decentralized context, it is evident that the District Assembly does not have enough authority and resources to effectively address land management activities. (The World Bank, 2008)

The decentralization agenda has taken a long time to take off in Ghana. Practical arrangements for sharing of duties and responsibilities between the DAs of Greater Accra and the Government remain to be defined and delivery of services to the population is hampered by a number of factors. Functional overlap between deconcentrated administration and DAs, use of secondment of deconcentrated staff to DAs, leaving DAs little influence on personal matters and training, and transfers making up 84 percent of DA revenues (which leave little incentive for savings), are all structural problems. Additional issues are, the fact that District Assemblies generate only modest amounts of internal revenues, that DAs budgets are not linked to investment plans, and that transfer systems favor small DAs, while capital expenditures in Greater Accra are approximately $2.7 USD per capita as compared to an estimated need of $80 USD per capita. (The World Bank, 2008)

This results in a situation where the larger DAs of Greater Accra are not able to provide services to their populations. Due to inadequate financing and management capacity, water coverage has declined in urban areas from 85 percent in 1990 to 61% in 2004. Solid waste management presents a huge expense on the DAs budgets but is still not functioning, with only 70 percent being collected. Transportation networks have failing levels of service across the metropolitan area and safety standards woefully substandard. The electricity sector is strained, which could result in reduction of GDP by as much as 0.9 percent per year. (The World Bank, 2008)

With respect to investment climate issues, firms in urban areas are constrained by a number of challenges, including the cost (in terms of fees and procedures) of starting a business anywhere in Ghana, registering a commercial property, enforcing a contract, going through bankruptcy and trading across borders. Small and micro enterprises are severely constrained by lack of access to credit. Additionally, inadequate infrastructure facilities and public services hinder the formation and growth of firms by increasing the cost of doing business, limiting access to markets, and reducing efficiency. A vibrant urban agglomeration with improved connectivity and productivity can help bridge the gap with the rural areas like trade, services, and employment. (The World Bank, 2008)

Perhaps the most important factor in the modernization of Ghana is the presence of modern electricity systems in its urban centers. Of all the western world’s appurtenances, none has a more profound potential to improve quality of life standards than a modern electricity infrastructure. The presence of electricity facilities supports all public infrastructures, from transportation systems to potable water and sanitary sewer services, from medical and public education to police, fire, and telecommunications. A reliable electricity supply is critical to the realization of a modern Ghana. (National Development Planning Commission of Ghana, 2005; United Nations, 2006)

Accra, Ghana is on the verge of becoming a megacity and thus facing critical decisions on which direction to take in the future. While its continued expansion could further fuel energy consumption demands, innovation in technology and urban planning could set up sustainable structures and guidelines for energy demand and production which would decouple economic growth from energy consumption, serve as a hospitable vehicle for poverty reduction and lead emissions from an exponential increase to at least a flattening growth curve.
1.4 Research Objective

Sub-Saharan Africa is urbanizing at a dramatic rate, which has the potential for many benefits as well as harms. Urban areas have great potential to serve as incubators of economic growth and engines of poverty reduction. Improved infrastructure is a significant component of promoting this growth in urban areas, and planning for improved electricity infrastructure can serve to increase GDP and average annual income, as well as be part of an enabling environment for economic development and poverty reduction. Focusing on electricity use in the cities of the Sub-Sahara is also important because urban areas in the developing world are projected to overtake OECD countries as the largest emitters of GHGs. Therefore developing a model for projecting the electricity demand of a major African city will serve as a foundation for quantifying the costs and benefits associated with proposals for economic development, poverty reduction, and environmental protection as well as acting as a template for other African cities.

The primary research objective of this work is to create a highly disaggregated property and land use urban simulation system for comprehensively projecting the electricity demand of the Korle Bu district in Accra, Ghana, in terms of low, medium, and high population and economic growth rates for the time period 2006 until 2025. In order to meet this primary research objective, the following secondary objectives will also be achieved.

1. To annually model household location choice by matching household attributes to preferred locations using a synthetically generated household population and the actual residential structures in Korle Bu.

2. To annually model commercial location choice by matching business attributes to preferred locations using a synthetically generated employment population and the actual commercial structures in Korle Bu.

3. To annually model the price of each individual plot in Korle Bu.

4. To annually project demographic and economic growth in Korle Bu for use in projecting low, medium and high growth scenarios.

5. To annually model electricity demand for each building and plot in Korle Bu, and then aggregate these demands to determine total projected electricity within the district as well as annual projected demand to 2025.

In total, these objectives comprise a single urban simulation system which describes every building and plot in the Korle Bu district for each year from 2006 until 2025, and thus enabling the disaggregated electricity demand projection.
Chapter 2
Modeling the City
2.1 The Science of the City

The study of the city falls under different names: City and Regional Planning, Geographical Sciences and Urban Studies, Town and Country Planning, Urban Economics, or Public Administration among many others. One of the reasons there are so many different approaches to studying the city is because understanding urban dynamics bridges many different disciplines of research. The Science of City and Urban Geography is interdisciplinary in nature; it includes economics and demographics, statistics and engineering, public policy and urban design, cultural studies and architecture.

The city can be defined in terms of its political boundaries as a subdivision of the state or by its contiguous urban area. Therefore, a city or town may have a politically defined boundary which is not coterminous with the urban area. Sometimes the aggregation of cities combine to create larger, continuous urban areas, while at other times, more rural municipalities, which are more similar to a district or a county, seek to include areas which are both rural and urban within their borders. The point being, cities generally have two different boundaries, one that defines the jurisdiction for a political entity which has some rights to govern within that area, and another that describes a contiguous urban area, which may be an aggregation of numerous political entities, on many different levels: local, county, district, regional, state or even national. The \textit{de facto} city is more concerned with the contiguous urban area and how those political entities function and govern.

The fundamental unit of a city is property. While a city is defined in terms of its boundaries, it is also subdivided internally, with all parcels having some form of ownership, whether private, public, permanent or temporary. Generally speaking, residential land uses, such as a single family home, is a singularly subdivided piece of property which is owned by an individual or family. A more complicated form of ownership involves condominiums or higher density residential land uses. Commercial land uses may also be individually owned by a person or business, but often some designated part of the property is leased to a corporation for a given amount of time. Industrial operations may also be owned or leased. Institutional uses are generally owned by the public, as designated within a governmental body. Finally, rights-of-ways and easements are a form of ownership designated for public and private infrastructures, such as highways and roads, electricity and gas, water and sewer, stormwater and drainage, as well as telecommunication facilities.

While property which has been subdivided into individual lots, parcels, or right-of-ways is the primarily unit of analysis, the primary means for describing these individual units is in terms of land use. There are four primary urban land uses: residential, commercial, industrial, and institutional. A parcel can also be described in terms of the existing use on that subject piece of property, for example, an apartment building may be considered as a medium density residential use. Furthermore, that existing use, may or may not comply with those uses which have been permitted for that subject parcel. This regulation of what is permitted on an individual piece of property is called zoning or sometimes current planning. A zoning designation serves to regulate what uses are permitted on a subject property, as well as the levels of density (residential uses which are measured in the number of dwelling units per acre or m\textsuperscript{2}) or intensity (commercial and industrial uses which are measured in floor area ratio which is a comparison of the total building floor area to the property area) which are permitted, among other things. Finally future land use planning guides the development of large areas within a city, district or region as to what types of uses and development are consistent with the vision for that particular area. One such example could be an area which has been designated for Intensive Development, where more intense industrial operations are permitted, such as a harbor or trucking terminal. Comparatively a future land use designation of Environmental Conservation indicates a community vision which involves protecting habitat and fauna,
indigenous or endangered species, or groundwater recharge areas.

Studying the city is interdisciplinary in nature, but the two primary disciplines which serve as the foundation for Urban Sciences are demography and economics. Demographics and the associated use of statistics has many uses, but from the perspective of city planning focuses on domestic activities of individuals and their associated households, which assumedly are located on residential land uses. Within the context of city planning, economics is focused on the analysis and classification of jobs and businesses, which are primarily commercial or industrial. Additionally, economic analysis also identifies whether a particular business is associated more with providing local services, such as a restaurant or barber shop as compared to a business that is more involved with services which are provided outside of the local region, such as an international legal or engineering firm. Institutions or public services are also an important part of the city. Institutional analysis can focus on: Public Education (Universities, Colleges and Schools); Public Health (Hospitals and Clinics); as well as Public Safety (Military and Police). Infrastructure analysis is often a synthesis of engineering, which involves the design and construction of facilities (transportation, electricity, stormwater, potable water and sewer, telecommunications, and sometimes even parks and recreation) with public administration, which is more concerned with programming and finance.

2.1.1 Simulating Urban Dynamics

To understand the dynamics of disaggregated demands, as exhibited by individuals, households or businesses located within a city, it is necessary to be aware that we are dealing with a complex system which is dominated by non-linear and interactive processes. Micro-level actions based on local interaction and their urban environment are responsible for the “emergence” of consumption patterns at a macro-level. While at the same time, changes in urban planning policies can create new opportunities and constraints which affect the micro-behavior of individual “agents” and influence the configuration of demand patterns. (Da Fonseca Feitosa et al. 2010)

The complexity inherent to disaggregated demands imposes serious difficulties to the use of deduction, intuition or hand calculation in the process of understanding this phenomenon. Regarding this issue, computer-based simulations have been pointed towards as the most appropriate tools for understanding complex systems. Complex adaptive systems (CAM) and multi-agent systems (MAS) in particular, represent a promising approach towards addressing the complexity of disaggregated demands. By nature, complex adaptive and multi-agent systems focus on individual behavior within a certain spatial environment and how the interactions of these individuals manifest in the construction of global frameworks. It deals with many autonomous and explicitly located entities, or agents, which react to their environment and make decisions according to a set of rules. (Da Fonseca Feitosa et al. 2010)

The Limits of Modeling Cities

One of the key questions facing urban modelers is exactly how much detail is needed. The mainstream trend in urban transport and land use modeling is more and more towards disaggregation. Activity-based travel models have become the state of the art and agent-based land use models are proliferating. There are persuasive reasons for this trend including a growing individualization of society, the increased dominance of urban life styles, and the tendency for location and mobility patterns which are more diversified. Disaggregate models capture this heterogeneity. Still, some have argued that such attempts at microsimulation for large modelling projects failed to deliver in time, did not become operational for anyone other than the author, got lost in data collection and calibration and did not reach the state of policy analysis or simply remained in the academic environment and produced only PhD theses. One argument is based on the idea that when models include more information than necessary, the actually become exactly what is being simulated.
“Simplifying assumptions are not an excrescence on model-building; they are its essence. Lewis Carroll once remarked that a map on the scale of one-to-one would serve no purpose. And the philosopher of science Russell Hanson noted that if you progressed from a five-inch balsa wood model of a Spitfire airplane to a 15-inch model without moving parts, to a half-scale model, to a full-size entirely accurate one, you would end up not with a model of a Spitfire but with a Spitfire”.

Robert M. Solow (1973)

This approach begs the question, how much micro is too much? Planners seeking to develop a more aggregate approach point towards constraints of data collection, computing time and stochastic variation and suggest that for each planning problem an optimum level of conceptual, spatial and temporal model resolution suggests to work towards a theory of balanced multi-scale models which are as complex as necessary for the planning task at hand and "as simple as possible but no simpler". (Wegener 2009)

In this work we tend towards higher levels of disaggregation and complexity, because the very systems we are simulating are in fact very complex. In fact many urban systems have already been modelled and can be observed as they operate in real time. Transportation monitoring systems are capable of observing traffic and trips as they occur, water and sewer systems can give real-time read outs of pressure and flow from a remote location, while children in schools can be monitored by their parents from their homes. Simplifying for the sake of simplicity does not necessarily result in better results, while likewise building a more complex simulation also does not guarantee results. Entity oriented modelling offers a new direction with a capability to synthesize discrete choice approaches with goal oriented and adaptive agent-based models within the context of an urban fabric of physical structures being modeled in real time. Furthermore, computer systems and programming languages has been developed which greatly expand the potential for speed and power.

Multi-Agent Systems and Agent-Based Models
The concept of (computational or software) “agents” stems from the fields of Distributed Artificial Intelligence (DAI) and Multi-Agent Systems (MAS). Common definitions of the term characterize them as autonomous, reactive, goal-oriented, or socially able, just to a cite a few. Agent-based models, instead, are most importantly goal oriented and adaptive, and are programmed with an element of learning which is inherent to the agent itself. In a multi-agent system, an agent may be assigned a value or utility, which is dependent on their actions within that environment, but a goal oriented agent may seek to maximize this value and can adapt and learn which actions to take in order to increase their value over time and thus reach a goal. The Erev and Roth algorithm is one example of learning programmed into an agent in order to adapt and reach a specified goal. (Weidlich and Veit, 2008)

Discrete Choice Models
Multi-agent systems for urban simulation systems rely heavily on discrete choice modeling, a path breaking approach to modeling individual actions which was pioneered in the 1970s with Daniel McFadden’s theory on Random Utility Maximization. This approach derives a model from the probability of choosing among a set of available alternatives based on the characteristics of the chooser, the attributes of the alternatives, and the proportional, relative utility amongst them. A household choosing among alternative locations in the housing market, which we index by $i$, can serve as a simple illustration of how discrete choice models operate within an urban simulation. Take for example each agent, or household, and assume that each alternative choice $i$ has an associated utility $U_i$ which can be separated into a systematic part and a random part.
The log of this denominator is called the logsum, or composite utility, and it summarizes the utility across all the alternatives. In the context of a choice of mode between origins and destinations, for example, it would summarize the utility (disutility) of travel, considering all the modes connecting the origins and destinations. Thus the logsum also has appeal as a comprehensive evaluation measure. (Waddell 2010)

\[ U_i = V_i + \epsilon_i \]

Where

\[ V_i = \beta \cdot x_i \] is a linear in parameters function
\[ \beta \] is a vector of \( K \) estimable coefficients
\[ x_i \] is a vector of observed, exogenous, independent alternative, specific variables that may be interacted with the characteristics of the agent making the choice
\[ \epsilon_i \] is an unobserved random term

Assuming the unobserved term is distributed with a Gumbel distribution leads to the widely used multinomial logit model.

\[ P_i = \frac{e^{V_i}}{\sum_j e^{V_j}} \]

Where

\[ j \] is an index over all possible alternatives
\[ \beta \] is estimated with the method of maximum likelihood

Form 2.1  Geometric Interpretation of a Simple Discrete Choice Model

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2.2 Platforms for Modeling Cities

Regional, urban, city and town planning is interdisciplinary by nature, therefore modeling approaches towards simulating urban dynamics have also bridged many different areas of research. Urban simulation systems trend towards a synthesis of econometric, agent based models with physical representations of urban designed real cities, as they change through time. Infrastructure models, such as those that forecast the dynamics of transportation networks or electricity systems, typically either make projections at a national or regional (supranational) level or focus on a singular infrastructure project within a neighborhood or district. Rarely do infrastructure models forecast dynamics within a boundary that is coterminous with a de facto urban area.

The challenge of simulating the urban dynamics of any large city, such as Accra, is to physically model all of the physical infrastructure, including the transportation systems, water and sewer (if they exist), solid waste, storm runoff, public health, safety and education facilities, as well as projecting the daily decisions of households and businesses as well as their associated life cycle as these units progress into the future. Finally, modeled physical infrastructures should animate their functions as if they were occurring in real time, or hypothetically if a change to the system is being proposed. The result is an urban simulation that synthesizes and employs components of economics and demographics, statistics and engineering, public policy and urban design, cultural studies and architecture. This is the comprehensive and complex nature of simulating urban system dynamics of cities as well as their interaction with suburban and rural areas within that region.

2.2.1 NetLogo

NetLogo is a multi-agent programming language and integrated modeling environment for developing multi-agent systems and agent-based models in the social and natural sciences. NetLogo was designed in
the spirit of the Logo programming language to be "low threshold and no ceiling," that is to enable easy entry by novices and yet meet the needs of high powered users. The NetLogo environment enables exploration of emergent phenomena. It comes with an extensive models library including models in a variety of domains such as economics, biology, physics, chemistry, psychology, system dynamics and many other natural and social sciences. Beyond exploration, NetLogo enables the quick and easy authoring of models. It is particularly well suited for modeling complex systems developing over time. Modelers can give instructions to hundreds or thousands of independent "agents" all operating concurrently. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals. (NetLogo 2010)

**Examples of Application**

One of the first works of real significance in the area of simulation modeling and development research was by Dr. Quang Bao Le. Le et al. developed an innovative and novel multi-agent system for simulating land-use and land cover change for an upland watershed along the central coast of Vietnam. Using Netlogo, Dr. Le developed his VN-LUDAS model, consisting of four modules, which represent the main components of the coupled human-landscape system in forest margins. Le et al. nested the bounded-rational approach based on utility maximization using spatial multi-nominal logistic functions with heuristic rule-based techniques to represent the decision-making mechanisms of households with regard to their agricultural activities. The agent-based architecture allowed integration of diverse human, environmental and policy-related factors into farmers’ decision making with respect to land use and presentation of subsequent accumulated outcomes in terms of spatiotemporally explicit patterns of the natural landscape and population. (Le et al., 2005)

State of the art simulation of urban segregation, as well the development of a highly sophisticated urban simulation system, is found in the work of Dr. Flavia da Fonseca Feitosa. Da Fonseca Feitosa et al. built upon previous work developed at the Brazilian National Institute for Space Research (INPE), while synthesizing the work of Bao et al. and important historical foundations (Thomas Schelling) for a parameterized and calibrated hypothetical application of anti-segregation policies in São José dos Campos, Brazil and its environs. Da Fonseca Feitosa’s MASUS, Multi-Agent Simulator for Urban Segregation, is a virtual laboratory built in the Netlogo programming environment to explore theoretical issues and policy approaches on segregation. Urban households are represented as individual agents that interact with one another as well as their environment while making decisions regarding whether or not to relocate as well as their actual location choice. Within this structure, urban segregation emerges from the complexity of interactions. (Da Fonseca Feitosa et al.)

Da Fonseca Feitosa et al. used this learning laboratory to explore the impact of income inequality and personal preferences on segregation, and found that decreasing levels of income inequality promote the spatial integration of different social groups within the city. Da Fonseca Feitosa et al. also conducted experiments to explore high-income families’ neighborhood preference and revealed that high levels of poverty isolation were maintained even when affluent households did not take into account the income composition of neighborhoods while selecting their residential location. Finally, Da Fonseca Feitosa et al. present results with regard to the equitable distribution of infrastructure investments on clandestine settlements as well as the potential implementation of social mix policies (poverty and wealth dispersion) in Brazil. (Da Fonseca Feitosa et al.)

### 2.2.2 The Open Platform for Urban Simulation (UrbanSim)

UrbanSim is a software-based simulation system for supporting planning and analysis of urban development, incorporating the interactions between land use, transportation, the economy, and the
environment. It is intended for use by Metropolitan Planning Organizations (MPOs), cities, counties, non-governmental organizations, researchers and students interested in exploring the effects of infrastructure and policy choices on a number of community outcomes. Unlike most multi-agent system and agent-based modeling platforms which have been developed in Java, UrbanSim was completely reprogrammed from Java to Python in 2007, due to the advantage Python has in terms of processing speed for the massive amounts of data that are normally associated with modeling large urban areas. (Waddell et al. 2010)

**Functional Description**

Structurally, UrbanSim is a system of models which predicts choices of individuals, households, and businesses. This urban simulation system relies heavily on discrete choice models for projecting residential, commercial, industrial and institutional location choice. Regression models are used to predict real estate price, while simple allocation models are used to determine exogenous variables such as population or economic growth. Each UrbanSim project has a fundamental spatial unit of analysis, either a parcel, gridcell, or zone, which is normally determined depending on the quality of data available. If comprehensive data is not available, for each and every unit, a synthetic population generator may be used to simulate needed tables, so long as certain statistical parameters are met. The resulting group of tables or baseyear data is then used as input for the models that run sequentially and comprise the larger urban simulation system. As each model is run, the baseyear data is updated to reflect the projected outcome, which is sequentially used as input for subsequent models until the series or annual cycle has been completed for that single simulation year. (Waddell et al. 2010)

Each urban simulation project is typically comprised of 4 different types of models which allocate jobs and households, determine if jobs and household will relocate, chooses where they will locate, and determines land value. These 4 types of models use the attributes of the fundamental spatial unit (parcel, gridcell, or zone) for the dataset (land use, land value, economic and demographic characteristics, and energy consumption) to estimate each model. The Economic and Demographic Transition Models

![UrbanSim Annual Cycle of Model System](image_url)
integrate exogenous forecasts of aggregate employment by sector and control totals for population and
households. As sectors grow or decline from the preceding year, jobs are added or removed from the
database. Likewise the demographic transition model approximates changes to affect the net result of
each time step. These models serve as the interface with an exogenous macroeconomic model. The
Employment and Household Relocation Models predict the probability that jobs or households of each
type will move from their current location or stay during a particular year. As the utility of different
locations increases or decreases as well as the value of the existing location, firms and households may
choose to relocate. Employment and Household Location Choice Models predict that a job or household
that is either new or has moved within the region will be located at a particular site. Buildings are used as
the basic geographic unit of analysis. Each job and household has an attribute of space that it needs and
this provides a simple accounting framework for space utilization within buildings. Households are further
defined by income level and the presence of children or family size. Land Value is modeled using a
hedonic regression of the log-transformed property value per square foot. Attributes of the parcel are
also used such as infrastructure availability, accessibility, density and neighborhood effects. (Waddell et al.
2010)

**Synthetic Population Generation**

UrbanSim is essentially an activity based microsimulation model system that recognizes that fact that
disaggregated demand (for transportation, water, electricity, goods and services etc...) is a derived
demand, where individuals undertake activities in time and space. The behavioral unit under
consideration is the individual person, thus leading to model systems that are capable of simulating
activities of individual persons over the course of a day, week, month and year. As activity-based
microsimulation model systems operate at the level of the individual, household and person attribute
information become necessary for the entire population within the study area. The problem faced by
urban modelers is that high quality comprehensive data is virtually never available at the disaggregate
level for an entire region or metropolitan area. However, a random sample from a survey is often
available and can be used to generate a complete synthetic population with comprehensive data on
attributes of interest. The activity based model system can then be applied to this synthetically generated
population to forecast disaggregated demand at the level of the individual person. (Pendyala et al. 2009)

Synthetic populations can be formed from the random samples by choosing or selecting households and
persons from the random samples such that the joint distribution of the critical attributes of interest in
the synthetic population match known aggregate distributions of household and person attributes. Using
a heuristic approach called Iterative Proportional Proportional Updating (IPU), synthetic populations can be generated

\[
\text{Minimize } \sum_j \left( \sum_i d_{ij}w_i - c_j \right)^2 / c_j \text{ or } \sum_j \left[ \left( \sum_i d_{ij}w_i - c_j \right)^2 / c_j \right] \text{ or } \sum_j \left[ \left| \sum_i d_{ij}w_i - c_j \right| / c_j \right]
\]

subject to \( w_i \geq 0 \)

**Where**

1 denotes a household (1, 2, ...8)

\( j \) denotes the constraint or population characteristic of interest (1, 2, ...5)

\( d_{ij} \) represents the frequency of the population characteristic (household/person type) in household \( i \)

\( w_i \) is the weight attributed to the \( i \)th household

\( c_j \) is the value of the population characteristic \( j \)

---

**Formula 2.2 Geometric Interpretation of the Iterative Proportional Updating (IPU) Method**
where both household level and person level characteristics can be matched in a computationally efficient manner. The mathematical optimization problem takes the form of Formula 2.2 depending on the objective function. (Pendyala et al. 2009)

**Multiple Regression Model for Projecting Disaggregated Demand of Public Services**

In order to project disaggregated demand for a specific public service (potable water, electricity, solid waste etc...) a multiple regression model based on property characteristics such as historic consumption, land use, demographic and economic data can be incorporated into the urban simulation system. A multiple regression model is a multivariate statistical technique, which examines the variable being forecasted (e.g. electricity demand) and multiple other variables in order to forecast the implicit nature of a dependent to multiple other significant independent variables.

When using a multiple regression model, it is important to minimize the correlation between predictor variables. If predictor variables are related to each other, a change in one variable will cause other variables to change, resulting in an exaggerated change in the dependent variable. This is the problem of collinearity. Although relationships between predictor variables may be unavoidable, an effort to minimize collinearity is important for maximizing the prediction power of the regression model. (King et al. 2006)

**Examples of Application**

UrbanSim is being formally used for planning purposes by a number of local and regional governments mostly in the United States. These city and regional planning organizations include Honolulu, Hawaii’s Oahu Metropolitan Planning Organization; Eugene-Springfield, Oregon as implemented by the Oregon Department of Transportation; the Houston-Galveston Area Council; the Regional Planning Agency for Paris, France; Seattle, Washington’s Puget Sound Regional Council; the San Francisco County Transportation Authority; and the Southeast Michigan Council of Governments. More recent application has included the SustainCity project which is being led by ETH and is developing a model UrbanSim based on Zurich, Switzerland as well as application in Johannesburg, South Africa, which is being funded by the Council for Scientific and Industrial Research (CSIR). Other academic institutions that are reportedly developing UrbanSim models are the Technical University of Berlin (Germany), the Universidade Federal de Santa Catarina (Brazil), Arizona State University (USA) and the University of Florida, among many others. (Waddell et al. 2010)

**2.3 Modeling Electricity Infrastructure**

Named the greatest engineering achievement of the 20th century by the National Academy of Engineering (USA), the electrical grid has been called the largest and most complex machine in the world as well as the largest industrial investment in the history of humankind. Electrical power systems are extremely intricate, comprising generation, transmission and distribution subsystems, and in order to keep modern
systems operating smoothly, different kinds of software are used at different operational stages and levels. For example, Supervisory Control and Data Acquisition (SCADA) and Energy Management System (EMS) software is used to supervise, control and manage generation and transmission systems, and Distribution Management System (DMS) software is used to manage distribution networks. (Sun & Tesfatsion, 2006b)

Electricity system analysis can be built around three conceptual layers comprising primarily actors, infrastructure, and zones. Actors are typically grouped in accordance with their legal identity, for example power generation companies, load-serving entities and independent system operator within the domain of wholesale markets. Likewise actors in retail markets are defined in accordance with their legal identity such as retail power distributor and consumers at their end-use. The technical layer is structured around the processing of resource stocks and flows, high-voltage transmission grids, low voltage distribution networks, as well as end use power consumption or production. Interconnected control domains are interfaced by gateways which reflect various types of legal contracts which may be managed by the ISO for wholesale transactions or possibly LSEs in the case of dual register meters (net metering). The zonal layer incorporates conditions that are more exogenous to the system such as weather, macroeconomics, or the site suitability for implementation of a new technology. (Morrison et. Al, 2008)

Because of the technical nature of the traded good, electricity markets rank among the most complex of all markets operated at present. Supply and demand have to be balanced in real time, considering transmission limits and unit commitment constraints. These complexities drive most classical modeling methods to their limits. Equilibrium models either do not consider strategic bidding behavior or assume that players have all the relevant information about the other players’ characteristics and behavior. Due to the difficult real-world aspects, such as asymmetric information, imperfect competition, strategic interaction, collective learning and the possibility of multiple equilibria, more and more researchers have been developing agent-based models for simulating electricity infrastructure and market dynamics. (Tesfatsion & Weidlich 2006)

2.3.1 Accounting Frameworks

Developed at the Stockholm Environment Institute, the Long range Energy Alternatives Planning System (LEAP) is a widely-used software tool for energy policy analysis and climate change mitigation assessment. LEAP is an integrated modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. It can also be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks. In addition to tracking GHGs,
LEAP is used to analyze emissions of local and regional air pollutants, making it well-suited to studies of the climate and the co-benefits of local air pollution reduction. (SEI, 2009)

LEAP is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems, where each requires its own unique data structures. LEAP's modeling capabilities operate at two basic conceptual levels. At one level, LEAP's built-in calculations handle all of the "non controversial" energy, emissions and cost-benefit accounting calculations. At the second level, users enter spreadsheet-like expressions that can be used to specify time-varying data or to create a wide variety of sophisticated multi-variable models, thus enabling econometric and simulation approaches to be embedded within LEAP's overall accounting framework. LEAP is intended as a medium to long-term modeling tool with most studies using a forecast period of between 20 and 50 years. LEAP is designed around the concept of long-range scenario analysis. Scenarios are self-consistent storylines of how an energy system might evolve over time. (SEI, 2009)

The advantage of LEAP is its simple straightforward approach to modeling energy supply and demand in a manner that is scalable to economies which are multi-national in nature (such as West Africa) or detailed down to the size of a large city or district within a city (such as Korle-Bu in Accra). The interface is very intuitive, user friendly, and instructive. It is also a very good learning tool and is being used by numerous developing countries for exactly that purpose. The general approach of LEAP is to aggregate data in an accounting framework, which doesn’t lend itself to highly disaggregated approaches which may incorporate large amounts of detail at the individual household or business level. It is also unclear how LEAP would operate when coupled with another modeling platform, such as those used to simulate urban dynamics. Nonetheless, LEAP is an excellent framework and is being used by the Ministry of Energy in Ghana, where a number of different models of Ghana’s energy infrastructure have been developed and deployed. (SEI, 2009)

2.3.2 Optimization Models

Ghana’s electricity system has been in the process of moving from a centralized structure based on set tariffs or contractual relationships between purchaser and buyer towards a deregulated one where wholesale trading and the various dynamics of supply and demand decisions dynamics are incorporated into the system. Optimization models are particularly useful for modeling centralized systems or decisions made by single organizations, such as in a centralized structure, but as Ghana plans to deregulate its electricity markets, more sophisticated models will be needed. The US based consulting firm Nexant technologies has developed just such a system for Ghana as part of the USAID funded West Africa Regional Transmission Stability Study. Nexant has developed two separate modeling frameworks, the Elfin optimum (Least Cost) generation expansion plan and the GE-PSLF model to project load flows and dynamic responses within the network. (Nexant 2005)

The Elfin modeling framework was developed to seek economical methods to increase the economic and environmental efficiency of energy investments, while the GE Positive Sequence Load Flow model is an analytical tool to perform transmission planning for load flow studies. Elfin includes generation planning analysis to adequately meet demand for electricity at a minimum cost through the incorporation of two main components: generation production forecast and generation optimization. The Elfin generation forecast uses a probabilistic load duration curve simulation method to dispatch resources to meet demand described by a load input curve, while the resource model makes allocations through an optimization process that includes iterative testing and life cycle cost benefit analysis. One of the main goals of the GE Positive Sequence Load Flow model is to design a large scale transmission system which operates in a safe and reliable manner. While Nexant Technologies’ modeling approach for the West
Africa Regional Transmission Stability Study is based on sound examples (including implementation in Florida, New York, California, France, China, and Indonesia) in many regards it is ideologically path dependent. This is particularly true in terms of modeling demand, which is largely aggregated and overly simplified. (Nexant 2005)

2.3.3 Equilibrium Models
Approaches which explicitly consider market equilibria within a traditional mathematical programming framework are classified as equilibrium models. Two common types are the Cournot competition, where firms compete in quantity strategies, and the Supply Function Equilibrium (SFE), where firms compete in offer curve strategies. Both models are based on the concept of Nash equilibrium, the market reaches equilibrium when each firm’s strategy is the best response to the strategies actually employed by its opponents. The SFE approach presents some advantages with respect to more traditional models of imperfect competition since it does not rely on the demand function, but on the shape of equilibrium supply functions. (North et al., 2002; Veit, Fichtner, & Ragwitz, 2004; Ventosa, Baillio, Ramos, & Rivier, 2005)

MARKAL (an acronym for MARKal ALlocation) is an example of an equilibrium modeling framework of energy systems that uses a technology-rich basis for estimating energy dynamics for one or several regions over a multi-period horizon. MARKAL was developed by the Energy Technology Systems Analysis Program (ETSAP), which is an extension of the International Energy Agency (IEA). MARKAL computes energy balances at all levels of an energy system: primary resources, secondary fuels, final energy, and energy services. The model aims to supply energy services at minimum global cost by simultaneously making equipment investment and operating decisions and primary energy supply decisions, by region. The choice of generation equipment (type and fuel) incorporates analysis of both the characteristics of alternative generation technologies and the economics of primary energy supply. The modeling framework takes into account global features as well as local decisions thus making MARKAL a vertically integrated model of the entire energy system. (ETSAP 2009)

Alam Mondal’s work at the Zentrum fur Entwicklungsforschung focuses on the relationship of economic development and sustainable energy paths in Bangladesh. Through the development of a MARKAL energy use model for Bangladesh, Mondal’s work examines the potential contribution of renewable energy to the future power supply mix under least cost analysis. The scientific innovation of his research is to specify national energy strategies which may arise in the further development of the Bangladesh energy sector with a special focus on renewable energy technologies. (Mondal 2010)

2.3.4 Multi-agent and Agent-based Models
Energy systems exist to provide industry, commerce, households and institutions with fuels and energy services. In addition to financial cost and reliability imperatives, these systems are now being asked to perform across a range of sustainability criteria. Most national systems fall well short on this second count and governments need to promote a suitable transition. The development of suitable public policy has necessitated the need for sophisticated simulation techniques, particularly considering the technical and commercial complexities involved, the multi-criteria nature of the policy problem, and the fact that most interventions will interact. (Morrison et al., 2008)

Agent-based simulations are an important next step from equilibrium models, as the problems under consideration become too complex for a formal equilibrium framework. Static models seem to neglect the fact that agents learn from past experience, improve their decision-making and adapt to changes in the environment (e.g. competitors’ moves, demand variations, or uncertain hydro flows). Integrated
simulation models can represent strategic agent decision dynamics by a set of sequential rules that can range from scheduling generation units and constructing offer curves to individual household and business decisions. Adaptive agent based simulation techniques can shed light on features of electricity markets that static models ignore and are helpful in the analysis of new regulatory measures and market rules. Multi-agent and agent-based simulation systems present the potential framework to explore the influence that repetitive interaction of participants exerts on the evolution of wholesale and retail electricity markets. (Tesfatsion & Weidlich 2006; Sun & Tesfatsion, 2006b)

**Entity Oriented Modeling**

Highly disaggregated and relatively literal energy system simulations represent an emerging field, as well as an important type of simulation system, which may also be referred to as a Complex Adaptive System (CAM). This type of high resolution, bottom up approach which not only includes each plant, connection, actor, decision and transaction but also the dynamic, networked infrastructure system is referred to as Entity-Oriented (EO) modeling. EO modeling is a style of simulation where all relevant entities in the problem domain are represented in a relatively concrete form. In terms of electricity power systems all relevant entities will generally include all actors and agents within the system: from the domain of high-voltage transmission, centralized power generation and wholesale markets; to low voltage distribution, distributed power generation, retail markets; as well as all the functions implicit to disaggregated demand at the fundamental level of analysis: the household, business, industry, or institution. (Morrison et al., 2008)

The advantages and benefits of entity oriented models are derived from their nature as a bottom up approach which is capable of accommodating high resolution, localized simulations that focus on sections of the overall system. EO models capture network dynamics naturally, because they are well suited to system architectures and institutional arrangements where these dynamics are likely to develop. EO models are also particularly useful for modeling demand, since demand from the most fundamental disaggregated unit of analysis is the primary driver of actions. EO models are also particularly useful for incorporating the idea of distributed management and distributed systems as well as modeling the network dynamics which arise from the capacitated nature of networks. This is an important advantage since it is also likely that future energy systems will be strongly status aware in order to respond to changing circumstances in an intelligent manner. (Morrison et al., 2008)

Despite being detail intensive, entity oriented models are not fundamentally difficult to calibrate, so long as adequate data is available. Comparatively, other models often require abstract causalities to be estimated and can be quite sensitive to inaccuracies. EO models are also capable of providing insight into the way energy systems might be prompted to evolve from their present state towards pathways of energy sustainability. EO systems modeling offer the ability to observe and understand butterfly effects within the system, how seemingly minor network dynamics can affect overall trajectories (such as in long-range weather systems). Finally EO modeling is very capable of integrating actor/agent based modeling for investigating fundamental interactions with social and economic systems. This type of bounded rationality is used to describe decision-making which sidesteps the doctrines of (Bayesian) maximized subjective expected utility and discounted profit stream, and instead recognizes that actors, whether domestic or commercial, have limited knowledge, limited information gathering and processing abilities and different preferences and perceptions as to future states of the world. (Morrison et al., 2008)

**Justification for Improving Empirical Derivations of Disaggregated Demand**

Energy demand forecasting is an essential component for energy planning, strategy formulation for sustainable futures and developing energy policy recommendations. The task is challenging in developing
countries where necessary data, appropriate models and required institutions are lacking. Most energy demand models focus on a single approach such as: econometric or end-use; demand analysis by focusing on elasticities of demand and their variability among or across studies; or comparison of forecasts with the actually demand of industrialized countries. To date, we are unaware of any work that has attempted to capture the broad range of approaches and their methodological underpinnings considering the policy perspective of the developing world. Furthermore supply shortage is quite common in developing countries for commercial energies in general and electricity in particular. Consumption does not necessarily represent actual demand due to the existence of unfulfilled or suppressed demand. Finally, the possibilities of “leapfrogging” technological developments render unhinge the developing world from the path dependence experienced in industrialized countries. (Bhattacharyya & Timilsina, 2009)

Projected energy demands are often found to deviate from the actual demands due to limitations in the model structure or inappropriate assumptions. One review of energy demand forecasts in the United States, found that most forecasts overestimated demand by 100%. The models employed suffer from a long list of limitations including burying analytical assumptions in “black boxes” which are difficult to evaluate and reproduce the results. Others use inaccurate characterizations of the behavior of economic agents or group consumers into a few representative agents that represent the millions of decisions made by millions of individuals. (Bhattacharyya, Timilsina, 2009; Craig et al. 2002; Laitner et al. 2003)

A weak quantitative means for projecting demand generally results in load serving entities passing increased costs downstream to retail markets. This is largely a result of strategic behavior in the wholesale electricity markets where each agent can potentially influence market prices by bidding above marginal cost. While a rational, profit-seeking behavior, wholesale electricity regulation permits this type of behavior when competition in the retail sector is not providing a counter-balance. (Weidlich & Veit, 2006; Ventosa, Baíllo, Ramos, & Rivier, 2005)

**Examples**

Researchers at Iowa State University have developed Open Source Software (OSS) of an agent-based framework for testing the dynamic efficiency and reliability of the U.S. Federal Energy Regulatory

![Figure 2.3 Feasibility analysis for 200 kWe neighborhood fuel cells operating in a range of configurations and control settings.](image)

**Key**
- DR: Reduction in heat demand (50%)
- FC: Fuel cells (200 kWc) and peak-load boilers
- SC: Solar collectors with seasonal storage (see below)
- WTn: Wind turbines (1.5 MW) comprising n units

Solar collector specification

storage volume

collector area

Figure 2.3 Feasibility analysis for 200 kWe neighborhood fuel cells operating in a range of configurations and control settings.
Commission’s (FERC) proposed Wholesale Power Market Platform. This framework, which is referred to as AMES (Agent-based Modeling of Electricity Systems), models strategic traders interacting over time in a wholesale power market that is organized in accordance with core FERC recommended features and that operates over a realistically rendered transmission grid. This state of the art agent-based wholesale market simulation uses a derived form of the Erev-Roth stochastic reinforcement learning algorithm for each profit seeking Generator, which learns over time which marginal cost function to report to the ISO based on the profits it has earned from previously reported functions. The AMES model demonstrates the inherent and quasi-monopolistic nature of power generation companies to collude and game wholesale electricity markets in the United States, while load serving entities, generally pass costs along to the consumer with end users being provided few if any choices. (Tesfatsion & Weidlich 2006; Sun & Tesfatsion, 2006b)

Researchers at the Technical University of Berlin have developed Xeona (extensible entity oriented optimization-based network mediated analysis) an object-oriented simulation environment where demand drives system evolution as it responds to market dynamics and public policy. Xeona has been used to assess how various schemes for different types of land uses in southern Germany can compete with district heat and electricity from the incumbent municipal utility. The study considered the merits of installing natural gas fired fuel cells for a block of low-rise apartment buildings as well as the potential network interactions with renewable energy opportunities, such as solar systems and wind generation. The study found that technological multi-criteria performance is sensitive to the quality of local integration. The study also found significant positive social externalities despite the fact that none of the proposed options qualified as a fully commercial proposition. (Morrison et. Al, 2008)