Energy System Development in Africa: The case of grid and off-grid power in Kenya

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Abstract

This research used a combination of a grounded theory approach and system dynamics to study the electric power system in Kenya and to model the feedback at work in the development of the system. The ethnographic study revealed the challenges faced by consumers in choosing between grid and off-grid power options. Examination of this challenge leads to the hypothesis that competition between the grid and off-grid markets is contributing to the low growth in power consumption and that there is the potential for off-grid to become the dominant option in the future. This theory guided the construction of a system dynamics model focusing on consumers' decision-making and their interaction with the operation of the system. I then used the model to explore the dynamics of the system through scenario testing.

There were two key outcomes from the model. The first showed that given the parameters chosen in most cases there is a clearly dominant option, although it changes over time. This finding points to the second key outcome the model, which is that there are realistic scenarios under which off-grid generation will become the dominant supply source. This shift could be induced by either reduced overhead on photovoltaic panels or high fuel prices. The outcomes from this research have implications for future electricity planning in Kenya and elsewhere in Africa. In particular, there is a need to decouple the system from external prices or account for the extreme uncertainty in fuel prices. Given the potential shift to large-scale off grid power generation, energy planners also need to look at options for managing a decentralized power system architecture and consider how to build in options for future reintegration if a large-scale centralized generation source comes online.

This research has both academic and applied contributions. On the academic side, it extends the range of engineering systems modeling to include qualitative factors found in an African environment. These factors include the addition of reliability and availability of the electric power grid and the biases in decision-making, which differ from those in industrialized countries. While the model clearly has direct application in Kenya, it was designed with flexibility to be expanded to include other countries and regions and could be a useful tool for understanding policy trade-offs in African electrification planning.

Doctoral committee: Professor David Marks (chair)
Professor John Sterman
Professor Richard de Neufville
Professor Roberto Rigobon

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Finally, in Ghana recently I was asked to make comments to a congregation about why it was important for young women to be given the opportunity to stay in school even when they could be helping at home. I told the group that educating their daughters was an investment in the future. I explained that my getting my Ph.D. started with my grandmother sending my mother to college and my mother making sure I knew every option was open to me. So, most of all, thank you Nana and Mom.

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Introduction

This research explores the dynamics of power system development in Africa, focusing on the interaction between customer decision-making and the technical system. To understand these dynamics I took a grounded theory approach, conducting fieldwork interviews in Kenya with power system stakeholders, then constructed a system dynamics model. The model shows the relationships between the stakeholder groups and maps the feedback within the system. It was used to explore the sensitivity of the system to changes and to experiment with potential future scenarios.

In sub-Saharan Africa the lack of access to modern energy sources is a clear obstacle to development and over reliance on traditional energy sources leads to environmental degradation, economic stagnation, and a decline in public health. Although most countries in Africa have had electrification programs in place for decades, planning and implementation have not been able to keep pace with the countries' economic and demographic shifts. The current population growth rate in most countries outpaces the rate of extension of electric services. While there are a myriad of reasons for why sub-Saharan Africa is behind the rest of the developing world in terms of infrastructure development, it is less clear why it is not gaining ground and moving forward.

Although the electric power grid is a technical system, its design and management is an engineering systems problem (Moses 2004). Large-Scale Socio-Technical Systems are defined as large, complex systems in which human and non-human elements interact, and where the social and managerial dimension tend to dominate (Marks 2002, Magee and de Weck 2002). African electric power systems have fewer technical components than most complex systems in industrialized countries, but have arguably a higher degree of social inputs and complexity. These systems are still in the early stages of development and, in many cases, rely on human capacity for operations. Creating a generalized model for system development in non-industrialized regions adds to the study of engineering systems, reveals new avenues of research within the Engineering Systems Division, and potentially benefits African energy planners.

Combined, the grounded theory work and system dynamics model show the potential shift in architecture of the Kenya system from a centralized grid to a decentralized system. The model shows this shift is unlikely to be predicted using the parameters currently used in Kenyan planning, but that it is more likely using realistic estimates of prices and preferences. In particular, power planning documents (Kenya Power and Lighting Company 2005, Kenya Power and Lighting Company 2006) use an unrealistically low projection for future oil prices. Other potential policy levers include taxes or subsidies on the price of photovoltaics and the choice of cooperation versus competition between the grid operator and off-grid system dealers. This research is focused on understanding a new way of approaching the system and represents a starting point for more directed analysis.

As introduction, Chapter 1 presents the background motivation for the research, describes the past attempts to understand energy system development in sub-Saharan Africa, and shows how the grounded theory and system dynamics methods were selected. Chapter 2 describes the fieldwork and grounded theory research. Chapter 3 presents a detailed description of the model and its basic outputs. Chapter 4 describes the scenarios explored using the model and discusses the policy implications of the dynamics identified through the research. The concluding chapter discusses the contributions of the work and offers potential areas of future study.

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Chapter 1

African energy systems: Challenges and opportunities

Introduction

There are an estimated 1.6 billion people without access to electricity (IEA 2003). Although access has improved in the past thirty years, there is still a significant gap between industrialized and developing countries. While Asia and Latin America have made significant gains, sub-Saharan Africa (SSA) is continuing to fall further and further behind (IEA 2003, 2006). Seventy percent of people in sub-Saharan Africa live in rural areas and rural electrification rates are shockingly low. In some countries, less than five percent of the population has access to electricity (Karekezi 2002).

Lack of electricity and modern fuels is directly linked to an increase in disease and environmental degradation, and economic stagnation. The result is extreme poverty and, frequently, political instability. While providing electricity access will not solve all these problems, it will move one aspect of a large system of underdevelopment in a positive direction.

While this research is intended to be generalizable across sub-Saharan Africa, it is based on a case study of Kenya and its power system development. Kenya was selected in part because of my past experience there. While working as a teacher in Nairobi in 2000-2001, I experienced power rationing first hand. During that stay, and on subsequent visits and research trips to Kenya, I also established a large network of contacts which facilitated this investigation. However, this was not the only reason for selecting Kenya. Kenya is typical of sub-Saharan Africa in that it has a small installed capacity, low population density, majority rural population, heavy reliance on biomass, and low electricity penetration, particularly in rural areas. Table 1 shows how Kenya compares to the rest of Africa by these measures (Otte and Chilonda 2002, IEA 2003, EIA 2005, IEA 2002)[1].

	Kenya	**Average for Sub-Saharan Africa**
Installed capacity (MW)	1232	614
Population density (p/mile^2)	49.8	25.9
Percent population in rural areas (%)	66.9	66.3
Percent of energy from biomass sources (%)	70	81.2
Percent with electricity (%)	15	24

Table 1: Comparison of basic energy facts for Kenya and sub-Saharan Africa

The primary difference between Kenya and its peer countries is the level of knowledge and deployment of photovoltaics (PV). Already in 1994 (van der Plas and Hankins 1998), it was estimated that 75% of the population was aware of the benefits of PV. Although reporting has declined in recent years, by 2000 it was estimated that more than

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[1] Average capacity excludes South Africa, including South Africa the average installed capacity is 1381 MW but South Africa accounts for nearly 60% of power capacity in sub-Saharan Africa.

100,000 panels had been sold in Kenya (Jacobsen, Duke, Kammen, and Hankins 2000). Only South Africa has achieved such a high level of dissemination, but they have used subsidies to support the market.

There is also a potential benefit to focusing on Kenya. Within this region, Kenya has the largest economy and infrastructure. It has the potential to influence the development of the other countries in the region. Already, Kenya, Uganda, and Tanzania are integrating their power systems under the East African Master Plan for Electrification (in draft form - Kenya Power and Lighting Company 2006). Kenya as a case study provides both one of the greatest challenges in electrification and one of the greatest potentials to generate positive growth in the region[2].

While using Kenya as a case study, the larger aim of this project was to better understand the challenges in and opportunities for understanding African energy system development. The following sections describe in more detail the motivation for working on energy systems in Africa, the literature on energy and Africa, the options for analysis of this system, and the methods selected for completing this project.

Motivation: Impact of poor energy services

The primary reason to study electrification is because of the range of impacts it can have on many of the problems hindering development in Africa. Although it is intuitive that improvement in the provision of electric power is a positive step forward in African

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[2] This research was completed shortly before the violence surrounding the Kenya election in late 2007 and early 2008. It remains to be seen whether the economy will fully recover to its leadership status.

development, there are specific connections between energy and development. This section describes some of the economic, social and environmental externalities associated with energy services in Africa.

Environmental impacts

There are two principal environmental impacts of the continued use of traditional fuels in Africa. The first is the desertification and land erosion caused by the removal of ground cover and the second is the production of greenhouse gases through kerosene and charcoal use. As biomass is collected for home energy use, the land is no longer protected against erosion and desertification. With no ground cover, rain washes out the nutrients in the soil and leaves it unable to produce agriculture. At the beginning of the 20th century it was estimated that 40% of Ethiopia's land was forest. Currently less than 3% percent is woodland (Ethiopian Energy Studies & Research Centre 2000). This deforestation is a problem for most of sub-Saharan Africa.

In the West African country of Mali, wood fuel is 90% of total energy consumed. Even with high urbanization levels, 70% of population is still living in rural areas in 2007. The landscape is continuously threatened by the advance of the Great Sahara Desert due to wood fuel consumption and within 60-100 years the wood fuel stock will be totally exhausted (Diarra and Akuffo 2002). Reducing biomass use through transitioning to modern fuels will ease this problem.

A second environmental impact of traditional fuel use is the effect on greenhouse gas emissions. Bailis, Ezzati and Kammen (2005, 2003) found that simply shifting the biomass use in sub-Saharan Africa to more sustainable harvesting could result in a 36% reduction in greenhouse gas emissions over the period from 2000-2050. The gains will be even greater if the countries can transition to modern fossil fuels for the primary energy supply. As it currently stands, 61% of greenhouse gas emissions in sub-Saharan Africa come from burning wood. Transitioning away from biomass use to modern energy sources will reduce the strain on the both the land and the air in sub-Saharan Africa.

Health impacts

Reducing biomass use and switching to modern energy sources will also reduce the strain on the people of sub-Saharan Africa. In the same study referenced above, Bailis, Ezzati, and Kammen (2005) found that in 2000 an estimated 51% of child deaths due to lower respiratory infections and 63% of women's deaths due to chronic pulmonary disease were caused by household use of biomass fuels. The real impact of this is 350,000 child deaths and 34,000 adult female deaths. Use of paraffin and candles in households also impacts population morbidity. If it is not stored properly, children are frequently poisoned by paraffin when they mistake it for water and drink it. Paraffin also produces a black smoke when burned which has similar respiratory effects to wood burning. Use of candles can result in home fires, resulting in both loss of property and loss of life.

Spalding-Fletcher and Matibe (2003) used data from South Africa to translate this relationship to economic terms. In 1999, they estimated the avoided health cost of switching to electricity were \$30 to \$400 million[3]. These figures are calculated from the direct health costs of biomass, paraffin, and candle use.

A final impact of electricity on health is in the provision of services. Health clinics that have electricity access can store antibiotics and vaccines more effectively and can perform important screening tests, such as x-rays. Better health services, and avoided death and costs due to non-electrical fuel use, improves the productivity of the labor force. Life expectancy can be considered an additional measure of human capital. Improving length of life improves human capital. Sachs and Warner (1996) analyzed the link between life expectancy and GDP growth and found that for countries with a low life expectancy, the effect of increased life expectancy on growth was higher than for countries with a long life expectancy[4]. For example, in Sierra Leone they found that raising life expectancy by one year (from 32 to 33 years) created a rise in average annual growth of 0.24 percentage points.

Economic impacts

There is some debate as to the causal relationship between electricity provision and economic growth. Wolde-Rufael (2006) published a regression analysis of economic growth and electricity consumption in 17 African countries (using the time period 1971-2000). While the paper could not prove a definitive causal link between the two variables, it found: "(1) past values of economic growth have a predictive ability in determining present values of electricity consumption in some countries, (2) past values

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[3] using 1999 conversion 5.8 ZAR = \$US, data found on http://www.x-rates.com

[4] In industrialized countries the impact is near zero since health improvements in those countries are more concerned with extending life past an age when the average person is less economically productive, whereas in poor countries health improvements are basic improvements in public health.

of electricity consumption have a predictive ability in determining the present values of economic growth; (3) there was a feedback in some countries and (4) there was a lack of causal relationship for some countries." These are hardly conclusive findings. However, the author also notes that the correlation is difficult to prove because the vast majority of the African population does not have access to electricity. This calls into question whether or not economic models can be effectively applied for proving this link.

The relative lack of access to power seen in Africa is one of the reasons it may make more sense to use either a dual-economy model or a model which accounts for fuel switching and traditional energy use[5]. Using current models, there are other studies which suggest the link between electricity and macroeconomic growth. Sachs and Warner (1996) looked more generally at causes of slow growth in African economies. While they did not look specifically at energy use, they did find that high incidence of disease and lower life expectancy will negatively impact growth. Agenor and Montiel (1999) also found, "inadequate infrastructure (in particular, electricity and water supply, the transportation network, and telephone services) is often a critical impediment to growth and may account for a substantial part of the low factor productivity that has often been observed." Additionally, Basu (2003) cites Majumdar and Mitra (1995) as having obtained an increasing returns model which establishes a critical level of initial stock that impacts the long term potential for growth, thus creating the same structure as the poverty trap. This difficulty in understanding the impact of energy systems in economic

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[5] Both of these elements are discussed in the development of the model in Chapter 3

development, and vice versa, turned out to be an important determinant of the boundary of the system dynamics model and is discussed further in Chapter 3.

Qualitative impacts

One of the challenges in African energy systems is trying to apply business rationality to the provision of a social right. Martin (2005) explored some of these issues by attempting a non-monetary evaluation of the health and education success of electricity programs. He found that electricity did reduce the risk of paraffin poisoning and increased the number of hours of studying, however, neither of these improvements make the system more affordable. The feedback from improved education to economic prosperity, even assuming more hours of study directly leads to improved performance in school, has a minimum delay of multiple years. Even if appropriate indicators of qualitative improvements can be determined, linking these improvements to affordability and investment in electricity is still a significant challenge.

A second challenge in measuring impacts lies in understanding who is a part of the system and who does not participate. As discussed in an earlier section, Wolde-Rufael (2006) found that the low use of electric power in industry lessened its impact on the economy. Similarly, the low penetration of electricity in most African countries excludes most of the population from its impacts. For example, in Karekezi and Kimani's (2002) analysis of power sector reforms in Kenya they found that the reforms had little impact on poverty because most poor people did not have access to electricity and were therefore unaffected by policy changes. This lack of participation makes it difficult to understand the impacts of electrification.

The motivation for improving electric power systems in Africa is based on the assumption that doing so will improve the quality of life for the population. Given the connections between improved energy services, environment, and human health, as well as the potential connection to economic growth, it seems apparent that electricity is a contributing factor in meeting development goals in Africa.

Literature review

Although the motivation for extending electricity services is clear, there is a gap in understanding energy system development in the African context. This gap is highlighted through a brief review of the existing literature on energy and Africa and the options for analysis. The review shows the need to step back from the existing models to better understand the dynamics of development at a systems level.

Problems and Solutions

Within the topic of energy and Africa, I identified two types of research and publications. The literature can be classified by how the author frames the problem of energy development. The first group, which I call the "intractable problem" group, presents the range of problems associated with lack of adequate power supply. Each paper generally discusses the difficulties in supplying power to developing countries (low population density, minimal ability to pay, inadequate investment in large-scale projects, and social and cultural failures in implementation), but does not offer solutions. For examples, see (Barnes, van der Plas and Floor 1997, Doig 1999, GVEP 2003, Holland et al. n.d., World Bank 2001, WEC and FAO-UN 1999). The second group, "simple solutions", presents one technology or model as the solution to the power problem. These papers typically cite at least one successful project and describe how its replication will improve many lives. Examples of model projects include the biogas digesters, microhydropower, and photovoltaics. Examples include van der Plas (1994), Senelwa and Sims (1999), Jacobsen (2007).

These classifications do not suggest that the authors do not understand the problem or provide excellent documentation of the issues involved in energy system development in Africa. Most of the papers reviewed were written by experts in the field and are based on solid experience working on African power systems. However, the body of literature fails to address the problem from a holistic, *systems* point of view. Electrification in Africa is a complex problem, but there are tools for managing this complexity. It is also unlikely that there is a single technology that is the answer. Even if there were one ideal method for electrification, over-reliance on one technology makes the system less robust and exposes it to greater risk of system failure.

A missing piece in addressing electrification in Africa is conceptualizing it as a complex system with interconnected technical, political and economic inputs. Karekezi and Kimani (2002) and Pandey (2002) have noted the lack of research in this field and the insufficient use of modeling in developing countries, respectively. Hammons et al. (2000) also cite this need with reference to the World Bank, saying that, "[it] has not yet found a reliable model for dealing with the special needs of sub-Saharan Africa electricity infrastructure." This gap is logically filled by engineering systems research.

Decision theory

My review of options for analysis initially focused on decision theory. While there is a wealth of literature on decision theory, here I have described the work most relevant to understanding the African context. The discussion of decision theory, and its limitations, led to an expanded examination of options for modeling and analyzing the development of power systems.

Under neoclassical economic rationality, agents make choices based on maximization of their own utility. This theory, first used by Bernoulli and greatly expanded by von Neumann and Morgenstern, assigns values and probabilities to various outcomes and states that a person will choose the outcome with the highest expected value (Mas-Colell, Whinston et al. 1995). Although this model of decision-making is technically advantageous, it frequently does not account for real human behavior as was shown by the Allais and Ellsberg paradoxes[6].

In application, especially in developing countries, utility maximization does not explain consumer behavior. Lipton (1968) found the context of a rural Indian environment created imperfections in factor allocation markets. These imperfections increased divergence between profit and utility-maximizing, impeded comparative advantage, and

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[6] The Allais paradox was one of the first challenges to the theory of expected utility. It was based on an experiment conducted through a survey of 'rational' men in 1952. The experiment results showed that under some lottery conditions, men would choose options which did not maximize expected utility[6]. Allais' findings led to consideration of the agent's reaction to the existence of known but not chosen options and the development of *regret theory* (Allais 1979). Out of this, risk preference was incorporated into the expected utility model. Using the function of a person's risk seeking or risk averse preference, this behavior could be used in calculating expected utility. The Ellsberg paradox, usually illustrated by selection preferences of different colored balls from an urn, shows that people have strong preferences for one gamble over another, even when expected utilities are the same (Ellsberg 2001). The preferences hold even when risk preference is accounted for, which shows this is a behavior that cannot be accounted for in expected utility theory.

perpetuated a pre-capitalist market structure. Much later, Humphrey and Verschoor (2004) examined the appropriateness of expected utility amongst farmers in East Uganda and found that it could not account for risky choice behavior[7]. Their findings show that decision-weighting models are more appropriate in this context.

Decision-weight models are one aspect of *prospect theory*, developed by Kahneman, Slovic and Tversky (1982). In this theory, the decision weight function is used to rank the outcomes from a value function. The value function is comparable to the utility function described above, except it accounts for how a person feels about gains and losses. One drawback of this theory, especially in the context of application in developing countries, is that it assumes agents know the exact probabilities of outcomes, given their choices. The Einhorn-Hogarth *ambiguity model* attempts to account for this failing, by incorporating a person's perception of the ambiguity and one's attitude toward that ambiguity (Hogarth 1987). This method relies on an ambiguity function, which is anchored on one probability outcome value. Although the theory captures the economic consequences of a person's inability to assess uncertainty, it still relies on the modeler's skills at creating a function that represents this perception.

Although expected utility theory has advantages in its simplicity, it is not suitable for describing decision-making for this research. The cognitive decision models can be used to account for a person's perception of losses, gains, and uncertainty, but they also rely on large data sets to create accurate value or ambiguity functions. It is even more

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[7] Their experiment showed 37% of observations were inconsistent with expected utility theory.

difficult to capture the context of the African environment, given that the models were developed industrialized agents in mind. This fact, coupled with the lack of substantial quantitative data sets, make it impossible to make accurate models of expected outcomes or risk profiles.

Options for analysis

Given the data limitations and the subsequent problems with traditional decision models, I reviewed other options for analysis. This review covered options for scope, method, and types of modeling. The preceding section on "simple solutions" shows that frequently the scope of analysis for African energy projects is quite small. Very often the focus is on one community or technology. Bradshaw, Kaiser, and Ndegwa (1995) suggest that this is one of the failings of African development models. They argue that the process is shaped by local, national, and global phenomenon and it is important to address the interaction between these levels, as well as the interaction among stakeholders within each level. The authors also find failure in the focus on deductive studies, citing Ndegwa (1992) that a "problem emerges because the frameworks and theories we employ are drawn from and driven by the parent discipline which, in turn, is located within a socio-cultural matrix that determines the relevant questions that should be pursued". They suggest scholars should seek an inductive method of research, building theories from field studies, as described by Glaser and Strauss (1967).

The primary options for inductive research include case studies and ethnographic studies. There are many examples of case studies of energy decision-making in Africa (Tatietse et al. 1999, Heltberg 2004, Aitken 2002). Each of these examples used surveys to extrapolate data from a population. Yet, data from the surveys is incomplete because it generally does not give the context of the selection[8]. There are also a couple examples of using ethnographic methods to study decision-making in Africa by Gladwin (1971, 2002). However, these studies focus on choices in agriculture practices. Ethnographic studies and energy choices are currently not linked despite the obvious need for context in modeling energy decisions. Buroway (1998) suggested an *extended case method* to extract macro-level ideas from micro-level observation. This method takes ethnographic findings to a more general level.

Generalizing the ethnographic work is particularly useful if the findings can be analyzed across a range of policy options. This is achieved through modeling of the system. There are numerous options for modeling, including both general methods for approaching problems with a high degree of uncertainty and methods specific to energy planning. The most complete review of African energy model is presented by Kagiannas et al. (2003), which covers eleven energy models for Mozambique. The models all fall within four categories: demand forecasting, supply side management of generation expansion, demand side management, and integrated resources planning. While the authors consider the dynamic nature of energy modeling, the models are all limited in scope. None take a systems approach, capturing how each of these elements interact with one another. Other options considered included a Real options approach (Gupta and Maranas 2004) and

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[8] As a personal example, when conducting a study of energy use in rural KwaZulu-Natal, South Africa, I found villagers' had a strong desire to have electricity for cooking, even when they could afford a gas cooker. The survey did not explain that this preference came from the perception that electric cookers are "modern" while gas cookers are "third world technology". This perception was so strong that even when I told people that I had a gas stove at my own house, and preferred gas over electricity for cooking, they thought I was lying in order to convince them to keep using inferior stoves. An ethnographic study of energy decision-making will reveal these contextual nuances.

multi-criteria decision making (Pohekar and Ramachandran 2004). Both approaches are well suited for managing the uncertainty of the African economic and policy environment, however are not dynamic in nature.

Many of the models are based on weak assumptions of how people in developing countries make decisions and work from the assumption of economic rationality. They are also focused on solving a single problem, i.e. energy planning for Mozambique in the case of Kagiannas et al. (2003). I wanted to construct a model which described the basic feedback in the system and was not so grounded in the details of the case study that it is irrelevant to other countries. This trade-off meant that the model would not have as much relevance to energy planners in Kenya, but would provide insight into the larger issues of power system development in Africa.

Methods of study

The review from the preceding section identified the gap in understanding the development of energy systems in Africa as complex systems. It shows the need to approach the problem from a systems level, looking at both the technical and human elements. The review of decision theory literature pointed to the need for understanding the context of decision-making and determining a way to approximate preference curves and the stakeholders' sensitivity to changes in the system. In looking at the existing models available, it is also clear that there is still a need for understanding the dynamics of growth in the African context. To address this need, I chose to use a grounded theory approach and system dynamics modeling. I focused on these methods because they brought together the systems level perspective with on-the-ground knowledge.

Grounded theory approach

I used a combination of the methods described by Gladwin (1989), Strauss and Corbin (1998), and Miles and Huberman (1994). The initial intent was to use Ethnographic Decision-tree Modeling (EDM) as the primary method, but during fieldwork the respondents converged very quickly on a central theme. The EDM proved useful for understanding the decision-making process among industrial consumers, but a more general approach was needed to understand the subtleties in the interactions among stakeholders. The following sections describe both the EDM procedure, and the general grounded theory method.

Ethnographic decision modeling builds on cognitive decision models, but uses ethnographic methods to empirically determine decision criteria. Gladwin (1989) describes the fundamental methodology, which includes creating a hierarchical decision tree based on studying the population group, then testing the model on different members of the same population. By this method, the researcher can capture the *expert* decision process and then validate the findings. The advantage of using EDM is that it captures the on-the-ground knowledge in a way that theoretical approaches cannot. However, it is not without its critics. Murray-Prior (1998) identifies two weaknesses, specifically, it does not explain the underlying motivation for behavior and the method is time consuming because ethnography requires multiple extended site visits. The first critique is valid, and Weller, Ruebush, and Klein (1997) found a similar issue when conducting ethnographic studies on medical decision-making in Guatemala. Their model, which was created through open-ended interviews, did not fully account for the factors affecting decisions. However, they believed more time and iterations would have improved the results. Another criticism comes from Mathews and Hill (1990), who say decision models are best applied in small, homogenous communities. In trying to capture decisions in a larger context the model is likely to have high error ratios. However, they also argue that "the presence of errors does not invalidate the decision process...these errors highlight the ways in which individual behaviors deviate from the group norms... [and] ultimately, a more complete understanding of both the social conditions structuring available options and of individual responses to those conditions is possible."

These criticisms are mitigated by what Murray-Prior considers the second drawback. The authors cited all referred to the need for more iterations and more time. Investing significant time in understanding the true motivations behind decision-making should not be considered a weakness of the method; rather it is evidence of a careful investigation. Ethnographic decision modeling is not a perfect solution to the problem of understanding the real conditions for decision-making under the uncertain conditions found in developing countries. However, it offers the best possibility of capturing the social and economic context of poverty, understanding decision-making under constraints, and integrating data in a system dynamics model.

System dynamics

The purpose of the ethnographic study is to develop a system dynamics model. The focus of this model is the interaction of decision-makers, within the technical system. Although most of the modeling took place upon return from the fieldwork, elements of the system dynamics method and the expected structures guided the ethnographic study.

Sterman (2000) found participant interaction and interaction with clients essential to formulating non-linear functions, which points to the use of interviewing and observation as methods.

There is a standard methodology for system dynamics modeling (Sterman 2000). This includes attention to stakeholder interaction, causal loop diagramming, calibration, and sensitivity analysis. There are many existing models of the electricity sector and technical systems which were used for guidance. Potential structures include: Diffusion of technology (Bass model), Decision-making, Pricing strategy, and Boom and bust[9]. As an example, the diffusion of technology model describes the spread of PV home systems in Kenya. Van der Plas and Hankins (1998) found that 94% of solar home system users they surveyed would recommend the system to a friend. This pattern of technology spread mimics the "word of mouth" function in the Bass model. Another example is the use of boom and bust in Andrew Ford's work on the electricity sector in California (2002). This model could be used to show the pattern of under-investment in Kenyan power generation.

Case study: Kenya

Figure 1 shows the basic structure of the Kenyan power system and the boundary of this study. The diagram shows the range of stakeholders in the system, which I investigated across four regions: Nairobi, Coast, Western Kenya, and Central Kenya. Essentially, there are two customer groups, industrial and residential, who purchase power from either off-grid generators (top) or the national grid (bottom). Transactions with off-grid

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[9] All as described by Sterman (2000)

providers are unregulated, but purchases from the grid are regulated by the Electricity Regulatory Board (ERB). Kenya's power operators are privatized, but only generation is unbundled and has open competition. Units of electricity are sold to Kenya Power and Lighting Co. (KPLC), who distributes the units and bills consumers.

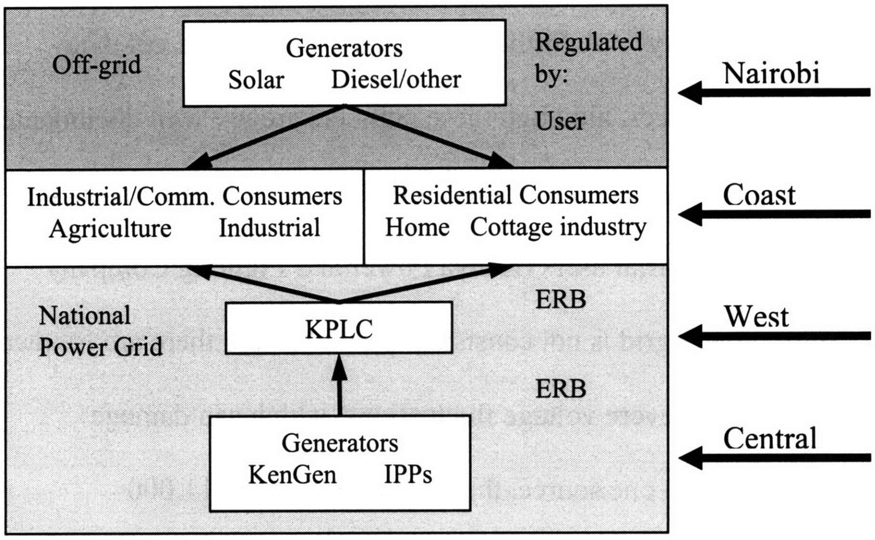

Figure 1: Kenya power system structure and study boundary

As of 2007, the installed capacity of the Kenyan interconnected grid system is 1,232 MW, and the total effective capacity is 1,121 MW. Of this, nearly 60% is hydropower, 32% is from thermal sources, and 10% is geothermal power. There is an additional 0.35 MW wind power and 30 MW imported from Uganda. The majority of Kenya's hydropower comes from the Tana River, where there are seven cascaded hydro stations ranging in size from 7.4 MW to 225 MW. Geothermal resources are located along the Rift Valley and all generation is currently in the Naivasha region (Kenya Power and Lighting Company 2006). Kenya Generating Company owns 83% of the generation and the remainder is owned by independent power producers (IPP). Several of these IPPs were brought in as emergency generators during prolonged power problems.

Kenya has more than 470,000 electric power customers, but the grid is focused on urban areas and over half the customers located in Nairobi. Still, only about 23% of urban dwellers have electricity access. However, this is high compared to the less than 1% of rural people with access to electricity[10]. A further estimated 2% of people get their electricity from off-grid power sources, although these numbers are not well documented. Large industry is the greatest consumer of electricity, followed by residential users and then medium commercial and industrial users (Kenya Power and Lighting Company 2004). The Kenyan electric power grid is not consistently reliable and there are frequent interruptions in supply, as well as severe voltage fluctuations, which can damage electronic equipment. According to one source, there are an estimated 11,000 interruptions per month (Hall 2006).

Industry accounts for 18.8% of the GDP (CIA 2007) and 74% of electricity consumption (IEA 2005). Principal industries of Kenya include: small-scale consumer goods, agricultural products (tea, coffee, and sugar), oil refining; aluminum, steel, lead; cement, commercial ship repair, tourism. Of these, tea, horticultural products (flowers), coffee, petroleum products, fish and cement, are exported. Several of these industries are electrically intensive, notably aluminum processing, cement, and tourism. Others, such as tea and coffee production, are thermal energy intensive. These industries, and their

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[10] These estimates vary widely, numbers used here were calculated by AFREPREN 2001 using World Bank and KPLC data

ability to have consistently available energy supplies, are one of the important links to economic growth in Kenya. Additionally, lack of power negatively impacts businesses which rely on electricity. For these reasons, it is important to capture the decision-making process of industrial energy consumers. The major production centers are Nairobi and Mombasa, and the tourist centers are generally in rural areas.

Although Kenya has been relatively politically stable since independence in 1963, this research coincided with one of the worst outbreaks of political violence following the December 2007 presidential elections. The unrest following the election was contained by early 2008 and a power sharing agreement was reached between the incumbent president and the opposition leader, both of whom claimed the election results had been manipulated. While the focus of this dissertation is on infrastructure, political stability does impact the development of the system. Stability is not accounted for in the model, but is discussed in the results section.

Summary

My approach to energy system development in Africa is designed to use system dynamics to understand the interaction between stakeholders and the technical system in Kenya. I chose to use a descriptive model based on grounded theory to identify potential leverage points where policy decisions could affect development. This approach fills a gap in addressing problems of sub-Saharan energy development from a systems level.

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Chapter 2

Using ethnography to understand power system development

Introduction

In order to better understand the factors that influence the development of the electric power system in Kenya, I conducted a grounded theory study of stakeholders in the power system. The study included more than 100 interviews with residential and industrial consumers, workers in the electricity industry, and small-scale power system dealers. Data was also collected from local media sources and participant observation. My analysis of the data suggests that electricity consumers face a difficult choice between grid connection and self-generation, based on the price and reliability of the options. It also shows there is potential for a large-scale consumer shift to off-grid electricity, but it is unclear what drives the shift and what will be the implications if it does occur.

Background

The goal of the methodology is to understand the dynamics of development of the electric power system in Kenya and the broader regional and infrastructure dynamics. Incorporated in this goal are three sub-goals:

- Understanding stakeholder decision-making
- Understanding the dynamics of the relationships among stakeholders
- Identifying key policy levers which control these dynamics

Each of these goals is grounded in the Kenyan case study, but will ideally have relevance in other regions and sectors as well.

Grounded theory method

The previous chapter introduced the reasons for using a grounded theory approach. This section discusses the application of grounded theory and methods used in the fieldwork portion of this research.

Data collection

Ethnographic methods range from textual studies, to oral histories, to formal surveys of populations. In this case, it was important to select methods which built an appropriate data set for a system dynamics model. Spradley (1980, 1979) is considered the general expert on these methods, but there are specific strategies for gathering data to fit a particular question.

Spradley's (1979) interview method is a twelve step process, beginning with identifying informants and ending with writing the ethnography. While his method is an exhaustive resource for planning fieldwork, it is most useful for general studies where the goal is to capture and record culture. Pawson (1996) discusses interviewing with a specific theory in mind. If the goal is to understand the context behind choices, a targeted approach such as the semi-structured interview described by Flick (1998) is required. Semi-structured interviews are guided by questions, but leave the response space and direction of the interview open-ended. Fife (2005) also discusses the practicalities of interviewing, specifically within the context of developing countries.

Much of the information about decision-making, however, is non-verbal. "Actions speak louder than words" and observations of actions can give more clues to behavior than interviews. Spradley (1980) specifically describes the ethnographic practice of *participant observation.* As compared to simple observation, participant observation requires the researcher to embed themselves in daily life among the subjects of the study. Dewalt (2001), Angrosino (2002), Fife (2005), Schensul (1999), and many others provide detailed descriptions of how to approach gaining access to a community and writing up observations.

Observation and interviewing do not each stand alone. Becker and Geer (1957) show how observation can reveal information that might not otherwise be gleaned from an interview. The reasoning is that the practices of some groups and individuals are so internalized that they might not think to mention them in an interview. Participant observation also has the advantage of showing behavior over time rather than capturing the experiences of an isolated interview. Used in combination, these methods can reveal both the person's perception of their choices and the reality of their actions.

In this case, interviews were the primary means of data collection[11]. These interviews were semi-structured and focused on planning and investment decisions, as well as energy use. A range of government and Power Company officials were interviewed, focusing on decision-makers. These interviews were primarily based in Nairobi and were requested through letters of introduction from existing contacts. For the industrial and commercial consumers, I interviewed facility or operations managers in the sectors identified previously. Finally, private energy and electricity dealers were interviewed to determine their role in energy development. The latter groups were interviewed both in Nairobi and in three other regions (see map in the Appendix).

In each case, I worked with the interviewee to determine a model of decision-making. This was an iterative process, as described by Gladwin (1989), and I tried to interview multiple stakeholders from each category. All interview notes were hand-written and digital audio recorded and compiled electronically. They were coded according to the relevant information gleaned from the exchange and, when useful, hierarchical decision-tree models were created from the data. The goal in selecting the interviewees was to speak with multiple representatives from all of the stakeholder groups. This meant conducting interviews with residential, commercial, and industrial consumers in each of

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[11] Clearance for interviews of human subjects was obtained from the MIT COUHES office and interviews were conducted according to COUHES guidelines.

the four KPLC regions, as well as talking to grid and off-grid generators. It was not possible to do a full random sample, so the goal was to speak with representative groups.

The first interviews with industrial consumers were focused on diversity in location and size. As the central theme of grid consumption versus self-generation began to emerge, I also targeted industries that were considering or had implemented self-generation schemes. Many of the interviews were conducted with the assistance of KPLC. The head office in Nairobi and regional offices in Kisumu, Nyeri, and Mombasa were extremely helpful in arranging visits to industrial consumer sites. Although there is an obvious potential conflict from having a KPLC representative present at the interviews, it actually proved to be an asset. The interviews conducted with a KPLC representative present were generally more detailed and animated. I believe this was the result of both the legitimacy the power company added to my request and the consumer's view that this was an opportunity to voice their concerns to someone official.

Residential interviewees were found through my own social network in Kenya and through contacts developed in the regions where I was working. In Nairobi, the interviewees were primarily connected to the school where I had previously worked. This group was selected because they represented a range of income levels, from maintenance workers to administrators, and because of the level of trust established by the fact that I had worked there. Almost none of the interviews were conducted with people I knew personally, but the interviewees were comfortable with me because of my connection to the school. Residential interviews in Kisumu were conducted with the assistance of a local bicycle taxi operator. The taxi operator was hired as a "research assistant" in order to be able to reach a geographically wider range of households and to speak with a wider range of economic groups. In Nairobi, even persons in the lower income households speak English, but in western Kenya this is not the case. The taxi operator was selected for his ability to translate from Swahili to English when speaking to a few of the interviewees.

Although the intention had been to conduct similar interviews in the coastal and central regions, this was not possible. In both areas I found residential consumers less willing to talk openly about their home energy use. In these areas I was not as able to draw on personal contacts so was only able to conduct a few interviews, which I deemed insufficient to make generalizations. In planning the residential fieldwork, I had expected KPLC would assist with customer interviews, however, they ended up being much more helpful with the industrial portion of the interviews instead.

Off-grid electricity technology dealers were found using contacts in Kenya. Many were also found simply by walking around town as they are generally centrally located in order to attract customers. It is a sign of the prevalence of the off-grid market that the businesses were so easy to locate. The exception to this rule was the coast region. In the Mombasa central business district there was only one visible solar home system dealer. The owner informed me that people on the coast were either rich enough to have grid electricity, or too poor to afford solar. He stated that photovoltaics was a technology used by wealthier farmers "up country"[12].

Although the ideal range of informants was planned prior to the fieldwork, it is important to realize that the ethnographic study was an iterative process. While the residential interviews did not end up being as extensive as planned, they were also not pursued as vigorously because the data had already started to converge on what would be the central theme of the study. Additionally, some interviews were conducted that had not been planned. I had not intended to speak to the Kenya Tea Development Agency (KTDA), but through other interviews found out that they were investigating a large scale self-generation project involving twenty of their tea factories. As a result, I spoke with managers in KTDA to understand why they were planning to generate power on site.

Each interviewee was asked several introductory questions, and then asked to elaborate on his experience. The interviewees each signed permission to be interviewed. Many of the respondents declined to be recorded or to have any information about them released. During the interviews I took notes, and then elaborated on my notes when the interview was finished. Later, these notes were typed up and coded according to themes. In these coded notes I also recorded my impressions of the interview and how the responses fit into the larger context of the research. Most interviews were conducted on site and in person, but a few had to be done over the phone due to logistical difficulties. Nearly all interviews were also conducted in English, which is the co-national language in Kenya.

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[12] Rural areas are frequently referred to as "up country". Many urban Kenyans retain close connections to their rural homes and go "up country" to visit family.

A few of the residential interviews were conducted in Kiswahili with the help of a translator[13]. A sample of the guiding questions is found in the Appendix. As with the selection of interviewees, the range of questions was also an iterative process. Through the course of the fieldwork, the questions became more targeted.

Data collection through observation took several forms, including personal experiences, observed practices and actions by locals, and immersion in local media. Personal experiences included my own observation of power outages, corruption, and uncertainty in Kenya. For this I drew on both the fieldwork experience in 2006 and my past experience in Kenya. Both these experiences also provided information on the customary practices of Kenyans. I attempted to record observations about local attitudes towards electricity use and investment in electric appliances and electricity consumption. These were both passive and active observations, as some were taken from watching actions as an outsider, while others were based on conversations or interactions.

A final source of data was the local media, particularly newspapers, magazines and TV programs. Sources included *The Daily Nation, The East African, The Standard* (newspapers), *Business in Africa, The New African, BBC Focus on Africa, Finance* (magazines), and *NTV Jioni, KTN Leo,* and *NTV Nightly News* (TV programs). Media plays an important part in communication in Kenya and public notices, such as electricity interruptions, are posted in the newspaper.

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[13] These respondents also signed a COUHES release form translated into Kiswahili. Copies of both versions of the release form are found in the Appendix.

Data analysis

Following the interviews, I expanded on my notes taken during the session and, in some cases, transcribed the recordings. I then summarized these notes according to the key details which stood out in the conversation. From these notes I was able to code concepts which I could pull out of the interviews. These concepts were then grouped according to larger thematic ideas. This coding process made it possible to see similar ideas across the interviews and to the then sort the themes accordingly. Some themes were specific to a certain type of interviewees, such as large industrial power consumers, while others were more general.

Grounded theory in practice

The analysis of interview data converged on central category of the tension between grid and off-grid power system development in Kenya. The grounded theory approach should be thought of as a funneling process, starting from raw data and narrowing through coding, categorizing, and defining a central category. Although great care was taken in accurately recording and interpreting the data, all interview and observation descriptions are my own. All informants were extremely generous in their willingness to be interviewed and any misrepresentations are solely my responsibility.

Fieldwork data

At the end of the fieldwork, I had conducted over 100 interviews with electricity stakeholders. Table 2 shows the number of customers in each category on the consumer side.

Consumers						
Regions	Large	Large	Medium	Medium	Residential	Small

	Commercial	Industrial	Commercial	Industrial		Business
Nairobi	1	7	9	2	16	1
Coast	5	4	1	0	2	0
Western	1	2	2	4	11	0
Mt. Kenya	0	3	2	0	2	0

Table 2: Consumers by location and type

Figure 2 and Figure 3 show the breakdown of interviews by region and customer type. As expected, the greatest numbers of interviews were done in Nairobi and Western Kenya. This is due to the large industrial and agricultural processing facilities in each, respectively, and the access to residential interviewees.

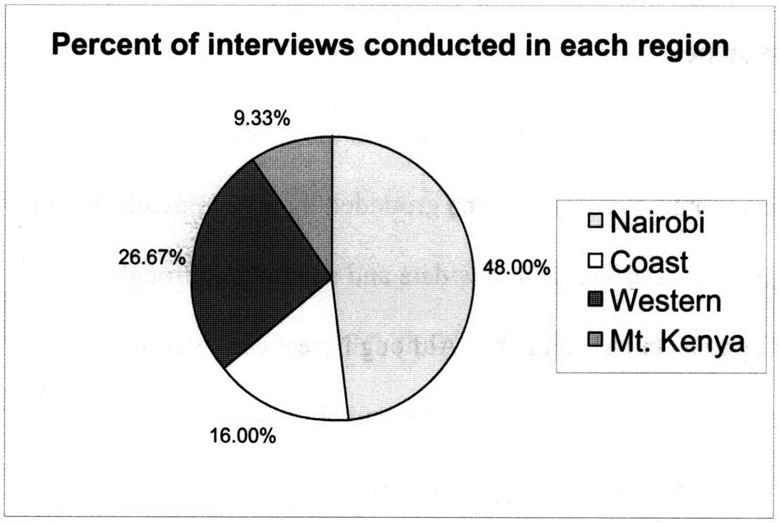

Figure 2: Range of customer interviews by region

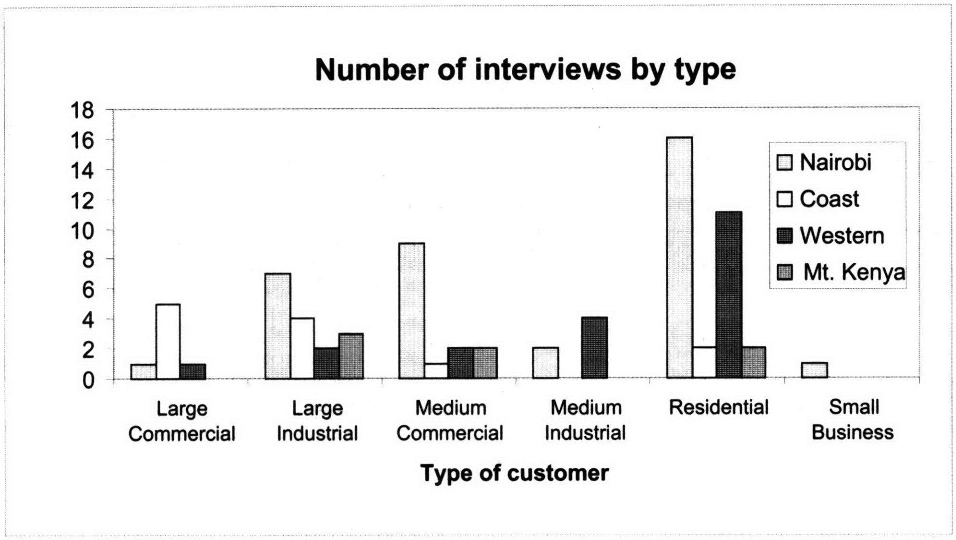

Figure 3: Number of interviews by region and type of customer

Additional interviews were conducted with Kenya Power and Lighting Company, the Electricity Regulatory Board, Kenya Association of Manufacturers, and Kenya Tea Development Authority. On an earlier research trip, interviews were conducted with KenGen and other stakeholders in KPLC, particularly the geothermal developers in KenGen and the rural electrification planners in the Nairobi office of KPLC. For the off-grid supply side, interviews were conducted with diesel generator and PV panel dealers.

I also collected contextual data from observations and media sources. The data collected was in the form of newspaper and magazine articles and written notes on observations. As a rough measure, over one hundred articles were eventually filed and categorized. Table 3 shows the range of articles collected. This categorization does not include articles collected on the telecommunications sector and power crises in other East African countries[14].

Categorization of observed media data		
Category	Number of articles	Sub-categories
Rural power	9	▪ Rural electrification ▪ Proposed ban on kerosene ▪ Environmental costs of diesel
Externalities to power supply	22	▪ Effect of energy prices on goods ▪ Economic growth ▪ Corruption ▪ Urbanization ▪ Cable theft ▪ Riots after power outage
Sugar company power producers	5	▪ Licensing of Mumias and Chemelil sugar factories
KenGen and KPLC	25	▪ Public offerings of shares ▪ Dispute over tariffs
Residential customers	20+[15]	▪ Notices of interruption of supply ▪ Advertisements for back-up generators ▪ Complaints against power company

Table 3: Categorization of observed media data

Similarly, 27 separate observations were coded and used in the development of the central category and theory. Similar to the interview process, the observations data taking was an iterative process. As the themes of the interviews began to converge around a central theme, the observation data collection became similarly more focused.

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[14] Both Tanzania and Uganda experienced power rationing in 2006, however these articles were deemed not directly relevant to this study.

[15] Representative examples of these advertisements and notices were collected, but they appear in the newspaper nearly every day. The number collected does not accurately reflect the frequency with which they are published.

Coding and sorting

Interviews were coded from the notes and recordings taken. The following is an example of interview coding from a food processing facility just outside Nairobi. Coding notes are in angle brackets.

> *Interviewer:*
>
> *Does the [business] figure out how much is lost due to interruptions?*
>
> *Interviewee:*
>
> *yes, we do, in fact some parts of our production if you get an interruption you can't just resume* <inconvenience of interruptions>, *you have to start all over again and that is a cost, we look at the cost of energy, cleaning, manpower* <external cost of electricity>, *it's quite costly for us, cost of diesel, if you interrupt for one minute, you can say that is four hours of lost production, if you're doing full blast we lose about half a million KSh per hour lost* <financial cost of interruptions>, *that is production you can never recover* <loss of production>, *you also have to add in cleaning etc.*

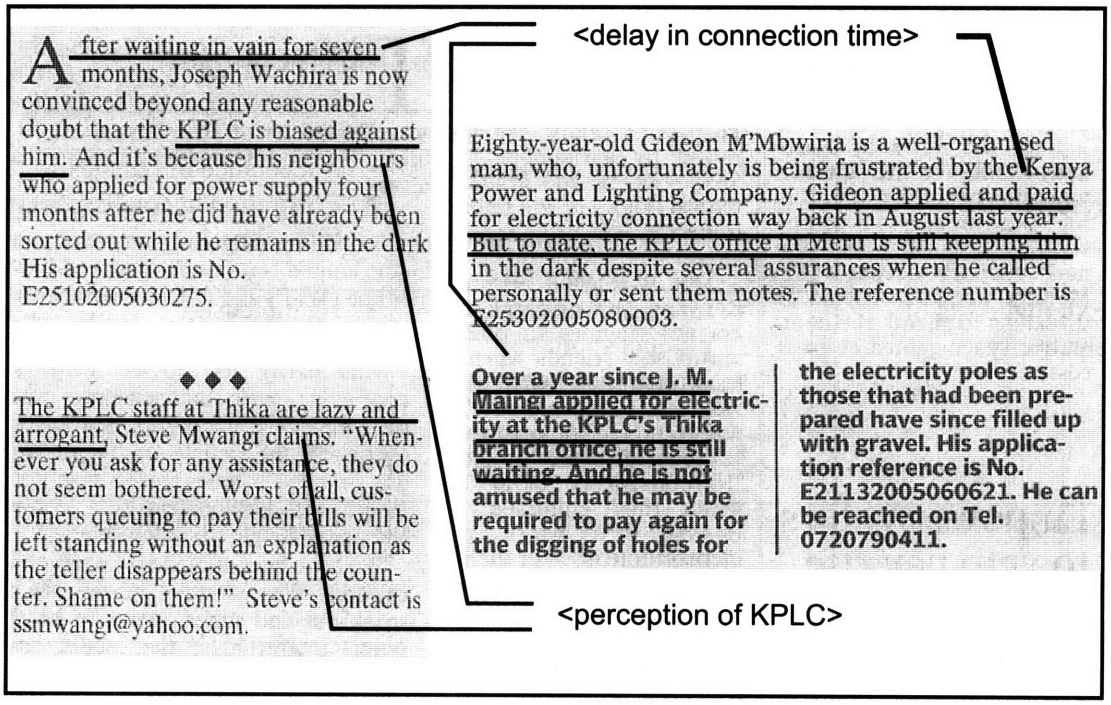
Each of these interview write-ups had similar concepts noted. The concepts were then pulled from the notes so they could be grouped by theme.

Observations included both visual observations, which were cataloged as notes, and media observations, which were collected. If the data was something that was solely observed, it was written down as a brief description of the event and coded using the same style as the interviews. As an example, one such observation was the reaction to a power outage at a very large supermarket was recorded as:

> *Power outage today at Nakumatt-Junction around 3pm. All lights went out except the emergency lights. There were a few sighs, but most customers simply paused where they were with their carts. Within a minute, the lights came back up and so did the hum of the appliance section. At that point I noticed that the overall noise of conversation resumed as well and that the store had been relatively silent while the power was out.*

This note was coded as <customer acceptance of power outages>. In my memo on the note, I commented that in the US a similar power outage would have prompted sounds of confusion, alarm, or at least interest. In Kenya, no one appeared to wonder what happened to cause the outage.

Media sources were coded in the same fashion. Figure 4 shows the coding from several complaints posted in the Kenyan newspaper (The Daily Nation 2006a, 2006b, 2006c). Since these sources could not be confirmed and it was not possible to know more about the context of the complaints, the comments were used primarily to confirm the interview findings.



After waiting in vain for seven months, Joseph Wachira is now convinced beyond any reasonable doubt that the KPLC is biased against him. And it's because his neighbours who applied for power supply four months after he did have already been sorted out while he remains in the dark His application is No. E25102005030275.

◆ ◆ ◆

The KPLC staff at Thika are lazy and arrogant, Steve Mwangi claims. "Whenever you ask for any assistance, they do not seem bothered. Worst of all, customers queuing to pay their bills will be left standing without an explanation as the teller disappears behind the counter. Shame on them!" Steve's contact is ssmwangi@yahoo.com.

Eighty-year-old Gideon M'Mbwiria is a well-organised man, who, unfortunately is being frustrated by the Kenya Power and Lighting Company. Gideon applied and paid for electricity connection way back in August last year. But to date, the KPLC office in Meru is still keeping him in the dark despite several assurances when he called personally or sent them notes. The reference number is E25302005080003.

Over a year since J. M. Maingi applied for electricity at the KPLC's Thika branch office, he is still waiting. And he is not amused that he may be required to pay again for the digging of holes for the electricity poles as those that had been prepared have since filled up with gravel. His application reference is No. E21132005060621. He can be reached on Tel. 0720790411.

Figure 4: Example of coding from newspaper source

The interviews produced 67 separate concepts and the observations produced 23 concepts. Where concepts were very similar, they were grouped together as one concept, even before looking at themes. Combining the data sets, there were 78 distinct concepts. These concepts were then categorized into smaller number of grouped themes. The range of concepts were categorized into four very general themes. The groupings had to be broad categories in order to capture the diversity of the respondents. The four primary themes seen in the ethnographic study were:

- Expectations of national provider
- External costs of electricity
- Sense of control
- Corruption and theft

Concepts and themes derived from interviews and observations		
Theme	**Industrial characteristics**	**Residential characteristics**
Expectations of the power system	▪ Electricity connection a privilege ▪ Planned interruptions fine if given notice	▪ Acceptance of outages ▪ Frustration at connection times, cost
External costs of electricity	▪ Interruptions cause product spoilage ▪ Interruptions damage machinery ▪ Voltage fluctuations cause injury	▪ Health costs ▪ Education costs
Sense of control	▪ Cannot control production ▪ Limited by costs and quality of power	▪ Commons problem
Corruption and theft	▪ Meter evasion ▪ Theft of components ▪ Kickbacks from investments	▪ Delays in connection

Table 4: Characteristics of themes from ethnographic data

One of the interesting themes to come out of the interviews was the Kenyan impression of the national power grid. Residential and industrial consumers are both faced with a choice of using the grid power supply or buying their own generating equipment. While this choice could be made based solely on financial comparisons, faith seems to play a role. KPLC is a former government parastatal and is still considered the "national" provider in many respects. Kenyans as a rule are not generally afraid to say how they feel about the government, and this forthrightness carries over to thoughts on the electricity provider.

Most industrial decision-makers described frequent interruptions and high costs due to outages, but most also said that "things were really improving". Several also indicated that they were fine with planned interruptions, as long as they had advance notice, but that the unplanned outages were causing problems. In one case, a steel production facility complained that the unplanned outages were dangerous to the workers and that there had been injuries when the equipment interrupted without notice. The fact that these types of problems are "accepted" shows the wide gap between the expectations of supply in Kenya versus an industrialized country. Several industries observed that they could not seek reparations because the wording of electricity contracts did not guarantee service.

Since the majority of residential consumers I spoke with were grid-connected or had no power, I gathered information on off-grid consumers from solar home system and diesel generator dealers[16]. The sellers described many customers as reluctant to invest in off-grid because they believed that the grid would be coming to their village soon. However, others noted that "KPLC is a dream" and that solar PV will be the reality in villages for quite some time.

Indirect electricity customers, people who use the facilities powered by electricity, do not have high expectations of the power system. Each of the large commercial consumers interviewed stated that "customers don't even notice", when the lights go down. This

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[16] This was a logistical constraint. Most off-grid users are in rural areas and there is very limited record-keeping by the sellers, making it difficult to locate the customers. I was able to gather second-hand information from people in Nairobi who used off-grid options in their home villages.

statement was confirmed by the numerous outages I experienced. Each was met with resignation, but not protests. The manager of a golf club noted that customers would be unaware of the outage unless they heard the generators running, which is the real reason most people do not seem to mind the outages. Nearly all service oriented facilities, like shopping areas, hotels, and high-end apartments, must have back-up systems. Hotel managers noted that back-up power is “vital” to their operations. So, customers might protest more if there was not an already well established back-up infrastructure in place.

In the introduction the economic costs and benefits were discussed. However, in Kenya the cost of poor electricity service can be directly measured. Of the industrial consumers interviewed, seven specifically mentioned that the power interruptions damaged the products in production and that they experienced losses. Of these companies, five produce food products and two produce plastics. Other industries reported that they did not lose product during the outages, but that production ceased. Six of the industrial consumers specifically mentioned that their power demand was too high to justify the purchase of a generator for back-up. One example is a pipeline pumping facility with a peak demand of 2 MW. Installing a back-up generator of that size would be a very significant investment.

The high cost of electricity and interruptions also hurts industry’s ability to compete outside of Kenya or East Africa. Electricity costs in Egypt and South Africa are significantly lower, which lowers the overall cost of goods. Three industrial customers specifically mentioned their inability to compete outside of the region. Two others stated that they had lost business due to high power costs. A further two customers (one overlapping respondent) were considering relocating due to a country with lower infrastructure costs. Two customers (again, one overlapping) also noted that they worry about meeting production due to power outages. Most of the industries operate 24 hours a day during peak periods so any down time is lost production.

One of the key themes to come out of the ethnographic study for both residential and industrial consumers is the concept of the sense of control the user feels with regard to power supply. In the industrial case this was the feeling of control over interruptions and cost and for residential consumers it was the feeling of control over quantity of consumption and cost. As discussed in the preceding section, industrial consumers did not have expectations of a constant power supply, but they were bothered by the number of unplanned interruptions. The unplanned interruptions lower the level of control the businesses have over planning and meeting deadlines for production. Most of the industrial consumers also expressed anger over the fluctuating price of electricity based on the fuel surcharge. Nearly all also expressed that they would not run diesel generators full time because they could not predict what the price of fuel would be in the future.

Residential consumers were also dismayed by the lack of control over fuel and electricity prices. Several respondents admitted that they had tried to use electricity for cooking or water heating, but that they stopped after seeing the first bill. One consumer in western Kenya said that she preferred to use a gas cooker because that way she could more easily observe her usage. In the shops that sold both PV panels and diesel generators, the owners said that customers would make their purchase based on whether they were willing to deal with the uncertainty of future diesel prices. This theme of control helps explain why PV sells so well in rural Kenya. Although the upfront cost is very high, the expected future costs are very easy to predict.

Other additional costs are also hard to predict. According to Transparency International, Kenya is ranked 150 out of 179 countries in terms of level of perceived corruption (2007). It is not surprising that lack of investment or theft in any sector is loosely blamed on "corruption". Corruption, as described in the interviews with stakeholders, falls into two main categories: petty theft and large-scale theft. Petty theft includes reading meters incorrectly or not at all, hiring unqualified family or friends, while large-scale theft typically involves diverting funds from large infrastructure projects.

The most notable form of corruption according to residential consumers was the delay in connections from the electric power company. Many people described how they, or someone they knew, had paid the connection fee and then been made to wait months or years for the power to actually be connected (see Figure 4). Although many of the interviewees felt that political connections would have helped speed up the process, one of the employees at the Electricity Regulatory Board I spoke with had been trying for two years to get his "up-country" home connected.

A second very obvious form of corruption was the direct theft and vandalism of power system components. A recent estimate revealed the extent of the problem. KPLC stated in June 2007 that 404 transformers were vandalized in the preceding 18 months (Otieno 2007). This level of vandalism was costing KPLC up to KSh 200 million per year. Table 5 shows some of the quotes from interviewees regarding the concepts included in the four themes.

Themes	Sub-themes	Representative quotes
Expectations of the power supply	Necessity of standby generators	"it is vital" (Food, Nairobi) "we can't afford not to have it" (Commercial, Nairobi)
	Customer acceptance of power outages in commercial centers	"they don't even notice, you see them continuing to shop by emergency light because they know the generator is coming on" (Commercial, Nairobi) "club members don't even notice unless they hear the generators" (Commercial, Nairobi)
	Mixed expectations of the grid	"the rural people still believe KPLC is coming so they don't want to buy solar" (Solar, Nairobi) "KPLC power is a dream, solar is the source for 10-20 years at least" (Solar, Western)
External costs of electricity	Power cuts reduce the competitiveness of Kenyan products by raising the end price	"the cost of electricity is one-third as much in South Africa, so their milk comes here but we can't sell ours there" (Food, Nairobi) "with electricity costs so high we can't compete on an international level" (Industrial, Western)
Sense of control	Consumer control of electricity use	"if the landlord even sees us using an iron he makes noise, the power

		"I don't use the electric cooker, instead I use gas so I can control my usage" (Residential, Western)
	High cost of electricity holds back consumption	"if power were inexpensive, I would bake like crazy" (Residential, Western) "I have an electric cooker, but I'm afraid to use" (Residential, Western) "my bill doubles when I use the water heater, so I don't use" (Residential, Western)
Corruption and theft	Corruption and inefficiency are major problems in service provision	Newspaper articles on cable theft
Other, uncategorized	Off-grid knowledge is spread mostly by word-of-mouth	"if your neighbor has 20W, then you want 20W" (Solar, Western) "most people come after seeing another house with solar" (Solar, Western)
	KPLC fear of off-grid generation	"if they were not generating [on-site] they would give us a lot of business" (about Industrial) "we were afraid this IPP Westmont was just going to supply [Industrial], that was a big fear" "if they could mine coal we are sad" (referring to industrial consumers who currently have no option other than diesel)

Table 5: Examples of supporting quotes for main themes

All themes, both residential and industrial, converged on the issue of the choice between grid and off-grid power supply. The constant presence of power outages and the poor availability of grid electricity in rural areas meant consumers were continually assessing their power options. Most consumers felt they could not control their power supply or bills and that generating their own power was a way to take control. From the supplier perspective, KPLC was quite concerned with the reliability of supply and how that might influence the decision-making of large industrial consumers.

The grounded theory portion of the research produced a central theme of the dynamics of stakeholder interaction in the Kenyan electric power system. Both the residential and industrial interviews quickly converged on the choice between grid and off-grid options. From this theme, I developed a hypothesis about how the simultaneous development of the grid and off-grid systems relates to overall growth in the system. This hypothesis was then used as the focal point of developing a system dynamics model to explore the dynamics further. Further discussion of the hypothesis begins on page 68.

Study limitations

The ethnographic method has many limitations in terms of the range and validity of data. The broader methodological concerns were addressed previously, however, there were also limitations specific to the completion of this research and the potential for replicability. Two specific limitations were the range of interviews and the required background knowledge for completing the work.

The range of interviews was largely dictated by access. This, in part, influenced the focus on industrial consumers' decisions. Industrial informants tended to be more willing to talk and it was easier to set up formal interviews. Many of the residential interviewees were fairly reticent, especially when talking about the power supply if it was controlled by the landlord. One hypothesis for this reticence is the semi-structured format of the interviews. It is possible the response would have been better if I had a used a formal survey, but that would not have captured the reasons behind decision-making, only the decision. As it turned out, far more of the information about residential behavior came from my observations and from interviews with PV and generator system dealers. Perhaps because I was approaching them at their business instead of home, the dealers were very helpful in providing information about their customers. In some cases, I attempted to use this conversation to segue into their own home power use, but found the same reticence to discuss home power use.

In terms of replicability, the specific fieldwork plan carried out was only possible because of my past experience in Kenya. Working as a teacher in Nairobi and visiting on several occasions, once previously for research, made it possible to quickly understand the key issues coming out of the interviews. It meant that there was very little start-up time required for interview preparation and background research. In addition, it was an advantage procedurally because I already knew the channels to work through for arranging interviews and deciding logistics like transportation. If this work were to be repeated in a new setting, it would require significant investment in understanding the local context, prior to beginning the interviewing process. This is not an insurmountable problem, simply a limitation in the expansion of the project to other countries or regions.

While there were noted limitations to the method employed, the fieldwork was very productive. It successfully bridged the gap between the surface level understanding of the system as seen in aggregated data sets, and the real decision-making on the ground by stakeholders in the power system.

Framework for understanding development

The common theme that emerged from the interview process was the relationship between grid and off-grid system development. This overall theme was seen in the four sub-themes identified in the lack of control and high costs of grid electricity. The dissatisfaction with the system, along with the high external costs make off-grid options attractive. The lack of buy-in to the system, seen in the theme of corruption in theft, means there is limited loyalty to the grid provider and limited faith that the conditions will improve. The relationship between grid and off-grid systems has several important elements. First, the development of the off-grid market is a reaction to the qualities of the grid system. For industrial consumers, the reliability and cost of the grid system makes it competitive to generate their own power. For residential consumers, the off-grid market is a reaction to the low availability and high cost of grid connections. In other regions of the world, off-grid technologies are not able to gain a foothold because the grid is available to most people. In general, household level power systems cannot compete on price with grid power. The only reason to choose an off-grid system is due to extenuating circumstances such as availability and reliability.

A second element of the relationship between grid and off-grid is the competition between the two systems. The relationship between the systems is explicitly seen as "tension" because of several elements of the interviewee responses on both the producer and consumer side. Specifically, Table 6 shows quotes which show this relationship. This tension is felt on both the producer and consumer side as the customers must choose between technologies where there is no clear winner and the producers target their rivals' markets.

Tension between grid and off-grid systems	
Source of quote	**Quote**
KPLC	"we were really fearing if they became a dedicated supplier" [refers to potential for former IPP to supply one of KPLC's largest customers]
Solar panel dealer	"this new program [Umeme pa Moja] is targeting our market" "KPLC is a dream, PV is reality"

Table 6: Evidence of tension between grid and off-grid sales

This tension between centralized and decentralized growth is not unique to Kenya. Personal experience with the South Africa off-grid electrification program showed that the grid and off-grid service providers operated in direct competition. Looking at the historical precedent, it appears even in urban areas of the United States there was a decision point between centralized and decentralized power systems. In Chicago in the 1880s there was a "divergence between central station generating systems and self-contained systems; many hotels, businesses, and factories purchased their own generators from Western Electric" (Platt 1991). The result was that no one could take advantage of economies of scale and prices for all stayed high. When Insull came in as manager of the largest central generating company, he used demand side management to reduce the cost per unit of the company down to the point where the others were driven out of business. Prices dropped for all, electricity was no longer a luxury, and electricity access expanded rapidly. The Chicago case shows a decentralized system converging on a centralized model, however Kenya is the opposite. The Kenyan shift from grid to off-grid represents a potential shift in system architecture.

The purpose of the ethnographic study was to better understand what is happening in Africa that could be limiting growth in electricity consumption. My theory, based on the interviews, was that most factors are the same as what has been seen in all other cases of electrification around the world, however, the level of competition between grid and off-grid is one potentially key difference. Based on this difference, my hypotheses are:

(1) In electric power systems with low initial penetration, competition between grid and off-grid providers can inhibit expansion of the system if there is no clearly dominant choice and

(2) There are realistic scenarios under which the system architecture will shift to a decentralized electric power system.

The implications of these theories are significant for power planning. The first implies that there is room in the market for interventions that could tip the balance to one option. The second also opens up the possibility of policy intervention. If off-grid becomes dominant it could shift the architecture of the national system and it is unclear if this would accelerate or hinder system development. Although the model presented in the following chapters cannot conclusively prove or refute the hypotheses, it is used to better understand the interaction of the stakeholders and to further explore the relationship between the grid and off-grid systems.

Validation and model building

As discussed previously, one of the challenges of the grounded theory approach is validation of the findings (Maxwell 1992). Although there is no absolute form of validation, in this case, the findings were confirmed by the rapid convergence of the central theme, a comparison to developing power systems in the region, and by confirming the observations with participants in the system.

The economic reasons for considering other options are clear. Cases from Nigeria and Egypt, among others, show the cost of poor electricity service (Adenikinju 2003, Lee and Anas 2002, Bernstein, M. and Y. Heganazy. 1988). There is also evidence that industrial self-generation is a viable option as shown by Gulyani's work in India (1999). Several authors (Nasen, Evertsson et al. 2002; Nguyen 2007) have speculated as to whether a decentralized or off-grid system architecture is more appropriate for developing countries, but have not explored the dynamics motivating the choice between grid and off-grid or the implications of that choice. There has been no investigation of the dynamics that would drive a shift to a decentralized system and the possible implications of a large number of customers switching from grid connections to off-grid power sources. This research presents a model developed to investigate this shift and the effect it could have on power system growth in Africa.

While there is not a historical reference mode for electrification which considers off-grid and grid options, there is a comparable trend in data on fixed line and mobile phones in Kenya. Based simply on price, mobile phones would have never been adopted in Kenya. At the time of writing (2007) it cost more than 30 KSh/minute for an average mobile phone call, but only 6 KSh/minute for an average fixed line call[17]. However, mobile phones have a great advantage over fixed line phones because of the portability and convenience. Sales are also increased by the status symbol of owning a mobile phone. However, initially mobile phones broke into the Kenyan market by offering availability and reliability.

A report in 2007 on the cell phone revolution in Kenya (Arunga and Kahora) tells the story of an entrepreneur who was one of the early adopters of the cell phone. He purchased the phone in the mid 1990s after spending six months and US$ 300 trying to get a landline connection. Although there was a public phone outside his home, it frequently stopped working and could not be relied on for business. The cell phone cost him over US$ 3000 (about eight times the annual GDP per capita in Kenya at the time) but he considered it a good investment because he could be connected immediately and could usually find a reliable signal.

As a result of the advantages of cell phones over fixed line phones, sales grew rapidly and Kenya's mobile phone providers are now among the most profitable businesses in the

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[17] Costs figures based on fixed line to fixed line and mobile to mobile (in network) peak rates from http://www.telkom.co.ke/TelephoneTariffs.htm and http://www.safaricom.com in 2007.

country. Figure 5 shows the growth in number of subscribers of mobile and fixed line phones over the decade from 1994 to 2004 (Mbarika and Mbarika 2006). While the number of fixed line subscribers grew slowly and linearly, the mobile phone subscriptions grew exponentially.

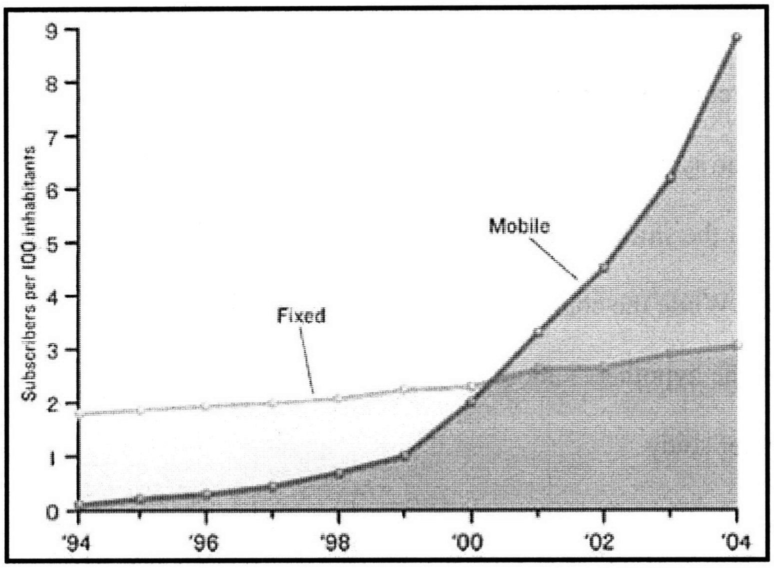

Figure 5: Growth in fixed line and mobile phone subscribers from 1994-2004

The electric power system will not necessarily follow this growth pattern. Mobile phones in developing countries are frequently seen as a substitute, as opposed to complementary, technology[18]. Few rural users will opt for a fixed line once they have purchased a mobile phone. It is not yet clear whether or not off-grid electrification systems in Kenya are complements to the grid, meaning they are used as back-ups, for specialized applications, or as a sowing technology which builds demand for grid electrification. Currently, off-

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[18] This point is debated in Hamilton (2003) and she presents evidence that in the beginning mobile phones are complements to fixed line, but that as the market matures they may become substitutes.

grid technologies are used primarily as a substitute technology in places where the grid is not available. There are also substantial network effects in the growth of telecommunications technology that are not present in power technology. These network effects make tipping point behavior more likely, where once one technology dominates it is harder to switch back to another.

The telephone case was used to communicate the potential dynamics of the power system to some of the stakeholders in the system. Interviewees from both producer and consumer groups confirmed that the shift to off-grid was a feasible scenario given the current state of grid electricity. While the comparative cases and discussions with stakeholders do not prove that the hypotheses about the system are true, they show that they are valid theories for further study.

Summary

The basic feedback between the grid performance and the reliability and subsequent development of the system was gleaned from the interview process and then confirmed through discussions with stakeholders and by comparison with similar dynamics both in other sectors in Kenya and in power systems in Nigeria and India. The grounded theory approach proved useful for identifying some of the development dynamics that are unique to the African environment and also identified non-technical variables, which are important to the system. The fieldwork data guided the design of the system dynamics model and added contextual detail to the relationships studied in the model. The next chapter presents the structure of the model.

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Chapter 3

Modeling the Kenyan Power System

Introduction

In an electric power system with high prices and low reliability, consumers are pushed to consider other options to meet their energy needs. Such is the case in Kenya, where both industrial and residential consumers have a choice between grid and off-grid electricity supply. This model was developed to better understand this choice and how it impacts the overall development of the electric power system in Kenya. It focuses on the potential "death spiral" for the grid power company, Kenya Power and Lighting Company (KPLC), due to customers shifting to off-grid options. Similar dynamics have been seen in the telecommunications sector in developing countries, as consumers shifted from fixed line to mobile phones. The model uses system dynamics methods and qualitative data from stakeholder interviews and field observations in Kenya.

The key finding from the modeling process is that there is potential for the "death spiral" to occur, but that there are balancing loops that prevent this dynamic from becoming dominant. There are circumstances that could push the system to override these balancing loops, which are explored in the next chapter. A second key finding from the model is the gap in feedbacks in the system. There are several areas where logically there would be feedback loops, however, based on the field study and other research, they do not exist. The impact of these feedbacks is also explored in the next chapter. This chapter reviews the system dynamics literature on electric power systems and infrastructure development, and describes in detail the model structure. At the conclusion of the chapter there is discussion of the insights gained through the modeling process.

Motivation

Inadequate and unreliable supply of electricity is a problem plaguing many countries in sub-Saharan Africa. These problems can have a devastating effect on both the economic and social development of the countries, as well as deter foreign investment. During fieldwork in Kenya, I identified a potentially large-scale shift from grid connection to self-generation among industrial power consumers, as well as potential growth in the off-grid residential power users, if the quality of grid power does not improve. This shift could represent the beginning of a downward spiral for the primary power company, if they are not able to maintain investments in generation and transmission capacity due to a loss of cash flow from customers reducing or eliminating their grid power consumption.

I chose to build a system dynamics model specifically to map the relationships between stakeholders, understand the impact of decisions and key variables in the system, and to be able to convey information about the system to policy makers. The first and third points in particular drove the decision to build the model. With many other modeling options it would be possible to determine the system sensitivity to variables and to see the impact of decision-making. However, system dynamics is uniquely able to represent the relationships in a clear visual representation, which can be easily understood by stakeholders and policy makers.

The model builds off the ethnographic work presented in the preceding chapter, as well as the system dynamics and sustainable development literature. The aim of the model is to inform policy makers and market stakeholders of leverage points that could be used to influence the development of the power system.

Literature review

The example from Chapter 2 on the telecommunications sector in Kenya illustrates the basic dynamic of the model. The larger structure of the model is grounded in the system dynamics literature, with modifications to account for the African context. System dynamics has been used extensively to describe issues of electric power system operations (see Ford 1997), however it has been used infrequently for applications in developing countries. Much of the system dynamics electricity work has focused on economic and regulatory issues, particularly capacity planning and privatization. Both are relevant to African power systems, but applying the same modeling approach to Kenya would assume that the analysis is building off a comparable system. Literature on energy system development in developing countries has shown there are some significant differences (See Chapter 1).

The most extensive work on modeling electric power systems using system dynamics has been done by Ford (1978, 1983, 2002) and Bunn, Dyner, and Larsen (1997, 1994, 2001).

System dynamics has been applied generally to the question of economic growth, but only in a few cases has it been applied to specific questions in developing countries. (Dudley 2002, 2003; Saeed and Prankprakma 1997). The most extensive investigation of infrastructure in developing countries comes from Saeed and Prankprakma (1997). The model in this case is a general model of infrastructure provision, focusing on the duality of developing country economies. Saeed shows the problem of relating economic growth to infrastructure development and the dual economy issue. This model makes the assumption that economic growth will be driven by forces other than the electricity system. This assumption is in line with the findings of Wolde-Rufael (2006), referenced previously in Chapter 1. This duality is still reflected in the Kenya model, however, in the separation of industrial and residential consumers. While the focus of the model is not economic, there is still a separation in the formal (industrial) and informal (largely residential consumers). The closest reference model for studying power systems in developing countries is Qudrat-Ullah and Davidsen (2001), which describes a model of generation in Pakistan. However, in that case the focus was environmental concerns, not development of the system.

Privatization is a topic of much debate in the electricity system dynamics literature. In developing countries, particularly Africa, the focus has been on unbundling generation from transmission and distribution and privatizing generation. Turkson (1999) and AFREPREN (2002) show the varying strategies for power sector reform across Africa, but there has been little evidence that privatization of the power industry has led to improvements. In Kenya specifically, the issues of privatization and regulatory oversight are discussed by Karekezi and Kimani (2002) and Nyoike (2002), respectively. As discussed in Chapter 1, Karekezi and Kimani found that reforms have had little impact on poverty because the majority of the country is not participating in the electric power industry. Models that focus on this issue would not be relevant to the Kenyan discussion. Nyoike found that despite the privatization of parts of the Kenya power industry and the creation of the regulatory board, the industry still operated as essentially a parastatal. This finding was confirmed in the fieldwork. Although the industry is in theory open to competition, the stakeholders on the supply side do not act with economic rationality.

The models developed for industrialized countries, with larger power systems and greater competition, are missing some of the context found in Africa. For example, one of these missing inputs is the population shifts still occurring in the developing world, especially Africa. As Youba Sokono, director of ENDA[19], noted in *Energy in Africa* (2004), "most African countries are faced with the critical challenge of meeting the energy demands of a population that, unlike many other parts of the world, has not yet completed its demographic transition." The demographics are still shifting due to intense urbanization and the effects of HIV/AIDS. These non-technical elements must be integrated into energy planning and decision-making. Another missing element is the issue of reliability. While most power system models assume only occasional faults, most African systems are highly unstable. Instead of starting from a model of guaranteed power provision, an African model incorporates reliability as a consumer decision point.

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[19] ENDA is the Environnement et Développement du Tiers-monde, a Senegal-based development think tank.

My model focuses on the behavioral aspects of the system by simplifying some of the economic, regulatory, and technical aspects. These assumptions are appropriate given that the purpose of the model is to understand the relationship between the power system and its user, which can then be used to better inform the ways to move forward with future analysis. The potential for additional research building off this model is discussed in the final chapter.

Feedbacks in the power system

The model was constructed with two primary feedbacks in mind, namely the effect of consumer decisions on reliability and the effect of consumer decisions on resource depletion and price. The model shows the impact of price and reliability on consumer choices in selecting grid or off-grid power sources in Kenya.

As consumers choose off-grid power sources, it reduces the cash flow for the power company and inhibits its ability to invest in new capacity. Lyneis (1975) describes this feedback as a capital rationing response to limited financial resources. Essentially, the company limits its cash outflow by limiting its acquisition of productive assets and growth is constrained by the subsequent lack of productive capacity. In Kenya, capacity constraints do not directly constrain demand, rather the constraints lead to unreliability and load shedding. This unreliability makes the grid less attractive and more consumers will decide to choose off-grid power sources (Figure 6).

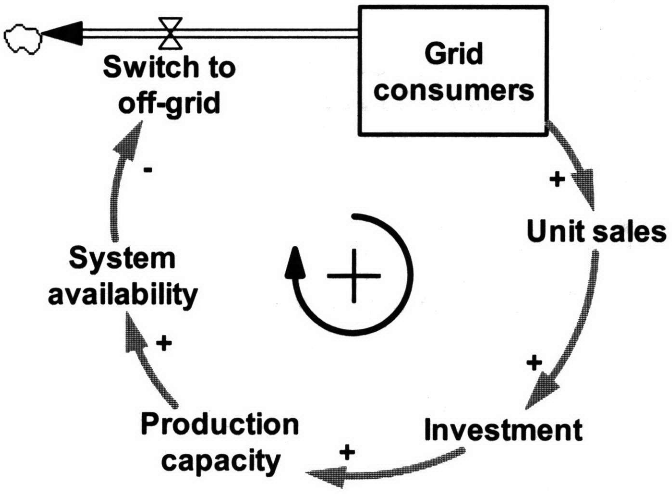

Figure 6: Reinforcing feedback from customers to system availability

Although the addition of reliability in the model distinguishes it from models of industrialized systems, users do not make a decision based on reliability alone. Price is also a significant factor in the decision. Some of the price estimates are based on exhaustible resources and therefore the cost of exploitation will go up as more of the resource is used. In Kenya, hydropower and geothermal energy are finite resources. As these resources are depleted, the cost of exploitation will increase (Figure 7). This feedback will impact both grid and off-grid sources as both will be drawing on the same resources.

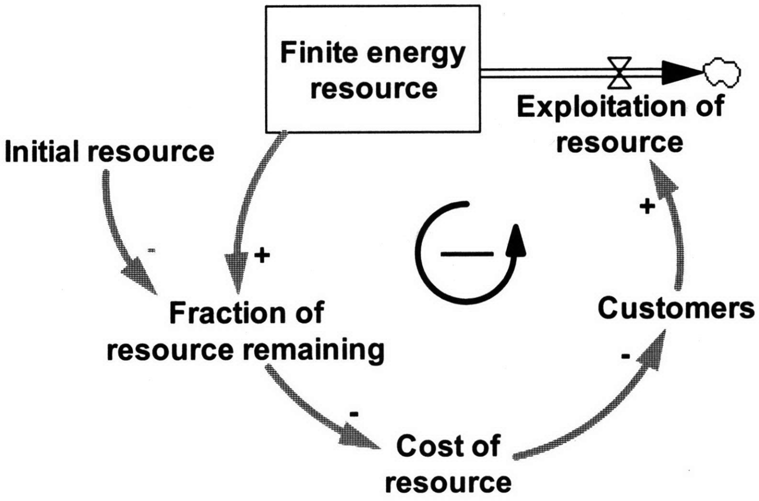

Figure 7: Feedback of rising costs due to resource depletion

A final secondary feedback in the model is the impact of the grid connection backlog on residential consumers. As long as the desired connection rate is greater than the actual connection rate, there will be a backlog of unmet demand. This backlog lowers consumer expectations of the availability of the grid and lowers the attractiveness of grid connection. This feedback was observed in many of the interviews with solar panel dealers, who said that their customers had applied for grid connections but became tired of waiting. In the interim they chose to purchase a diesel or solar home system. Others knew about the grid backlog before applying for a connection and opted for an off-grid option instead.

In the course of the modeling process, I identified several other feedbacks in the system, some of which were integrated into the model and some of which are potential extensions of the model. These feedbacks, as well as other lessons from the modeling process, are discussion at the end of the chapter.

Kenya power system model

The model can be divided into three components: the Decision Model, the Financial Model, and the Technical Model. Each of these components is further subdivided. The decision structure is divided into residential and industrial elements. Both consumer segments have two model components: a conditional logit function and an allocation function. The logit function determines the indicated market share for each electricity option. The allocation function keeps track of the stock of customers using each option, with flows in and out of the stocks governed by the indicated market share output of the logit. The financial model includes price calculations for the range of electricity options and the financial bookkeeping for the grid operator. The technical capacity components account for the planned and installed capacity of elements of the transmission, distribution, and generation systems, as well as keep track of the use of exhaustible generation resources. Figure 8 shows the overall structure of the model and the basic feedbacks in the system.

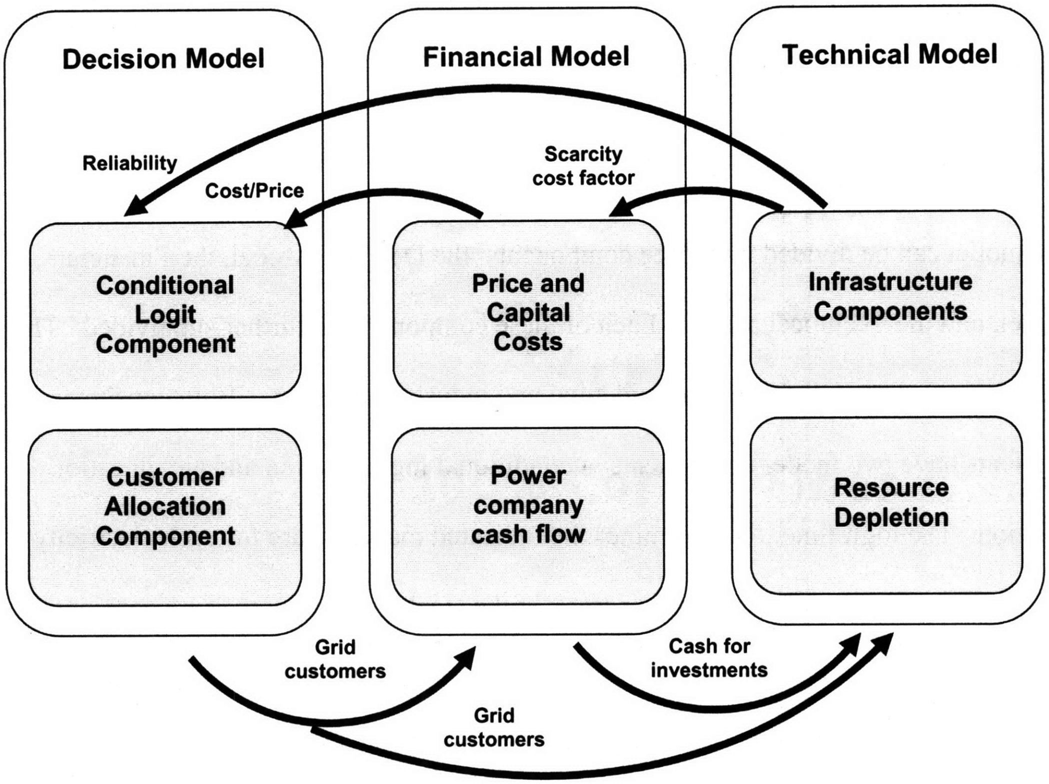

Figure 8: Model structure and overall feedback

The model structure reflects the high level feedbacks described earlier in the chapter. The number of grid customers is determined by the Decision Model, which impacts the power company cash flow in the Financial Model. This raises or lowers the quality of infrastructure components in the Technical Model, which then feedback into the Decision Model in the form of reliability. At the same time, the number of grid customers can deplete some of the non-renewable resources, which raises the price of electricity. This change in price is fed back into the Decision Model as well.

One of the primary trade-offs in the model is the depth of technical complexity versus clarity of explanation. Since the purpose of the model is to show the relationship between customers and the overall system, too much technical complexity would obscure the relationships. For this reason, in a number of places I assume simplifications of the power system operations. Each of these simplifications is noted in the description of the model structure and there are suggestions of how increasing the level of detail might affect the model. Some of these suggestions are options for future research areas, which are summarized in the final chapter.

Many of the structures of the model are based on commonly used structures for system dynamics modeling. Most of the structures are described in detail by Sterman (2000) and the explanations are not repeated here. In a few cases, elements of the structures were based on other models as described previously, such as work by Ford (1997) and Lyneis (1975).

Residential decision model

The residential consumer model is a basic model of technology diffusion and adoption. Interest in electricity spreads through word of mouth diffusion and adoption is based on a conditional logit function weighing of the relative merits of the options. Several details, however, make this model specific to a developing country environment. First, the word of mouth spread is constrained by poverty. Even though information about electrification will spread quickly, only a fraction of the population is potential adopters. This is similar to the constraint in technology diffusion for luxury goods in an industrialized country, however in this case it applies to basic infrastructure services. Similarly, the maximum capacity of connections is exogenously constrained in the Kenya model. This would be similar to a scarcity of goods seen in products in developing countries, except in that case the market will adjust to the scarcity and prices will rise and an equivalent competitor will enter the market. In the Kenyan case the product is more similar to a state controlled good and scarcity creates long lines and frustration.

There were several insights from the ethnographic study that appear in the Residential Decision Model. First, the ethnographic work identified the potential impact of the backlog in meeting grid connection demand. This perceived backlog is weighed, along with capital costs, unit prices, and reliability, by consumers in the decision model. Second, I identified a strong preference for grid service. Although there are frustrations with the service provided, there appears to be little possibility that a residential consumer will choose to disconnect from the grid to use an off-grid option. This is different than the industrial case, possibly because residential load is relatively low or because it is not tied to economic productivity in the household. A final insight from the ethnographic work was the definition of potential electricity customers. Several people interviewed were from very poor households and were not considering electricity as an option. Also, many of PV and diesel generator dealers commented on the spread of interest in off-grid units based on contact with neighbors who had purchased systems[20]. These elements of poverty and word of mouth spread were used in developing the model.

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[20] The finding about word of mouth spread is consistent with the findings of van der Plas and Hankins (1998)

Residential conditional logit function

The allocation of consumer market share is determined through a utility function, based on capital cost, operating cost, reliability, backlog, and quality of connection.

$$U_{ijk} = f_{jk}\,(Capex_i, Unit\ price_i, Reliability_i, Backlog_i, Quality\ of\ connection_i)$$

Where:

$$i = Options[Grid,\ Off\text{-}grid\ Diesel,\ Off\text{-}grid\ Renewables]$$

$$j = Attributes[Capex,\ Unit\ price,\ Reliability,\ Backlog,\ Quality\ of\ connection]$$

$$k = Population[Rural,\ Urban]$$

Capital cost, unit price, reliability, and backlog are calculated in other components of the model. The Quality of connection element was added to reflect the preference for grid-based power as the "modern" option and is exogenously determined. For the decision model the market share of each is determined by weighing the strength of options against one another. This is done by formulating the attractiveness of each. Attractiveness is based on the relative utility of each option. First, each of the attributes is smoothed so there is not a sudden transition to the expected value.

$$Expected\ value_{ij} = SMOOTH\left(Value_{ij}, Perception\ delay_j\right)$$

The Utility is then determined by multiplying the Expected value (divided by a reference value to normalize) by the Sensitivity of the customer to each attribute.

$$U_{ij} = \frac{Expected\ value_{ij}}{\mathrm{Re}\,ference\ value_j} * Sensitivity_j$$

The Attractiveness of the choices is the exponent of the utility:

$$A_{ij} = \exp^{U_{ij}} = \exp^{\frac{Expected\ value_{ij}}{\mathrm{Re}\,ference\ value_j} * Sensitivity_j}$$

Market share is determined separately for urban and rural populations using the Attractiveness of each option divided by the Sum of Attractiveness for each population.

$$Indicated\,share_k = \frac{A_{ij}}{\sum A_{ij}}$$

The output from this component is the indicated market share for each of the Options, based on the Attributes selected, indexed to include both Rural and Urban Populations. The market share is presented as a percent from 0 to 1 and the sum of all market shares must equal 1. These market shares are used to determine the allocation of residential customers.

Allocation of residential customers

I assume four stocks in the residential consumer model: Non-connected households, Grid connected households, Diesel households, and Renewable households. The stocks represent the number of households who are supplied by each power generation source, if any, and are initialized at Year 1995 levels. The Non-connected household stock accumulates new households according to population growth.

$$H = \int \frac{dH}{dt} = \int \frac{dP}{dt} \Big/ \left(\frac{P}{H}\right)$$

Not all non-connected households are potential electricity adopters. I assume a poverty constraint on households below the absolute poverty line. It is assumed that households whose income levels are below this line will remain non-connected. In the model this value is fixed at 53% of the population for rural households and 49% of the population for urban households (Kenya Central Bureau of Statistics 2000). The poverty value is assumed fixed because the future value is uncertain and there is no assumed feedback between growth in the power system and the population below the poverty line. As noted previously, the poor are unaffected by the reforms because they were not participants in the system (Karekezi and Kimani 2002). Electricity adopters will see an improvement in quality of life and economic status, but that will not directly pull other households above the poverty line.

Of the population of potential electricity adopters, the desire to have an electricity connection is assumed to spread based on word of mouth exposure to the benefits of electricity. This is a standard Bass diffusion model where:

$$Adoption = ciPA / N$$

The Potential Adopters (P), Adopters (A), and Total population (N) are known quantities. The Contact rate (c) and Adoption Fraction (i) are estimated. Since the actual contact rates and adoption fractions are unknown, they are set at $c_{rural} = 10$ and $c_{urban} = 20$[21].

Of the non-connected household population which could choose an electricity option, the number which select grid, diesel, or renewable is based on the attractiveness determined by the indicated market share structure. Figure 9 shows the basic structure of the allocation model, which keeps track of flows of non-connected households to different connection options.

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[21] This spread was documented by Van der Plas and Hankins (1998) who found 94 % of people were aware of photovoltaics and 85% of people had found out about PV from a neighbor.

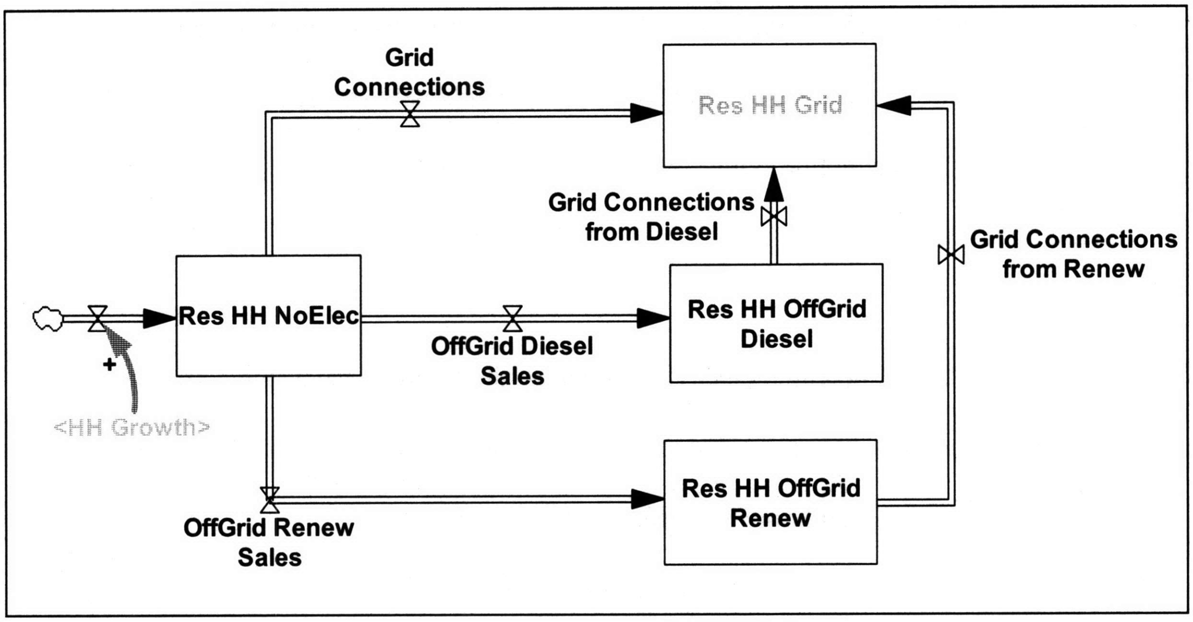

Figure 9: Basic structure of residential allocation model

The indicated shares allocation is the number of households that would switch into the Grid connected, Diesel, or Renewable households, given no other constraints. However, the number of grid connections is constrained by the power company (KPLC) capacity. Even if all residential consumers wished to be connected to the grid, this is not currently possible. The target for KPLC connections is exogenously determined based on the real current target of 150,000 new connections per year. For the immediate future, the demand for grid electrification will be far greater than the capacity of the power company to make the connections. This dynamic is explored in the scenario testing. For now, the maximum new grid connections capacity is:

PowerCo Connect Capacity = PowerCo Connect success % x PowerCo Conect target

With a target of 150,000 households per year and an estimated success rate of 80%, the maximum capacity per year is 120,000 households per year. One of the scenarios explored in the next chapter is what would happen if KPLC set their target based on demand.

When households are connected to the grid, it is not all from the pool of non-connected houses. Some of the houses with off-grid systems will be the most likely to want grid connections because they have already started to acquire appliances and they have a demonstrated level of wealth. Therefore, the Desired Connections to Grid population is made up of the fraction of new customers plus the people who want to switch from an off-grid source to grid power. The number of diesel or renewable customers who want to switch to grid is considered exogenously by shifting the percent of customers wanting to shift. Initially, all users are assumed to be happy with their decision and do not desired a grid connection once they have invested in an off-grid option. There is no outflow from grid to off-grid options, which reflects the strong feeling that the grid is "modern" technology and that the off-grid options are inferior. This preference was seen in the fieldwork and confirmed earlier findings from South Africa (Steel 2003).

There is a final subcomponent of the residential model, which keeps track of the proportion of the population in Rural and Urban areas. There are two stocks, one for Rural Population and one for Urban Population. There is fixed growth rate for each, based on the initial values for 1995 from the UN (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat 2007). There is a second flow from Rural to Urban based on urbanization. Figure 10 shows the basic structure which keeps track of population growth and urbanization.

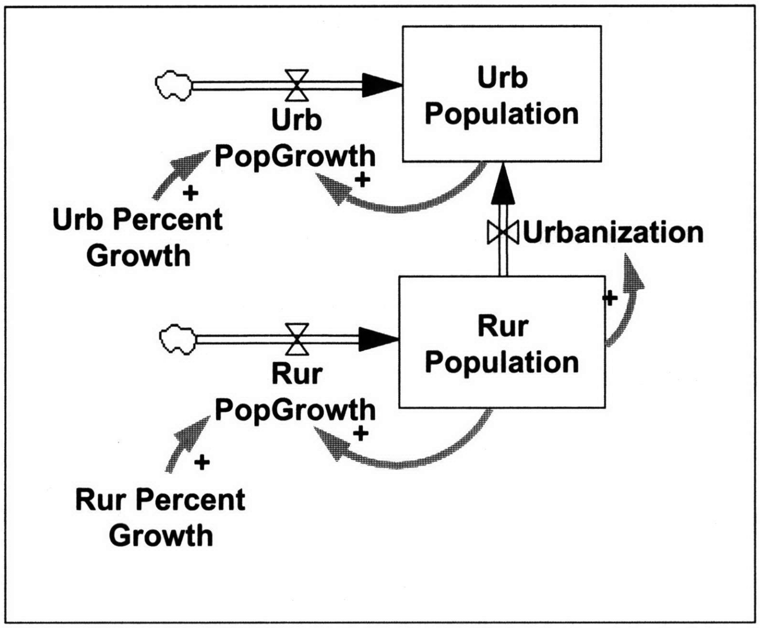

Figure 10: Basic structure of population subcomponent

The urbanization rate starts at the 1995 value, but will become smaller as the population reaches a equilibrium point. For the purpose of this model, that equilibrium point is set at 70%. As the population ratio of urban to rural nears 0.7, the rate of urbanization will slow. This represents a simplification of reality since it is much more likely that the urban population will overshoot the ideal before settling back to a sustainable level, likely through intense disease and poverty. This overshoot scenario is related to electrification in that access to public services is one of the motivating factors in the migration from rural to urban areas in Africa, however it is not important to the overall purpose of this model.

Summary of Residential Decision Model

The Residential Decision Model has two components: the Residential Logit Component and the Residential Allocation Component. The Logit function receives information on Reliability, Cost, and Price from the Financial and Technical Models and determines the Indicated Market Share for each of the electrification options, which is passed to the Allocation Component. The Allocation Component keeps track of the electrification status of households. If there is greater demand for grid connection than can be met by the power company, that perceived backlog is fed back into the Logit Component for consideration in choosing among the options. From the Allocation Component, the number of grid customers is passed to the Financial Model, where it is used to calculate Revenue to the power company. These relationships are summarized in Figure 11.

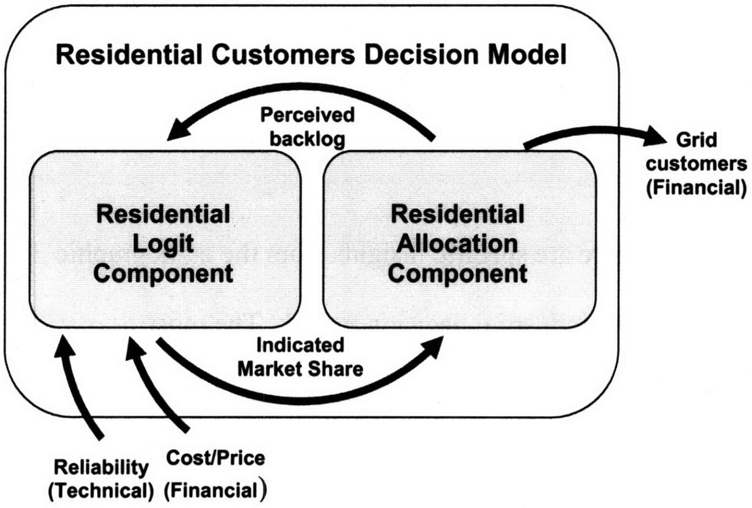

Figure 11: Residential Customers Decision Model structure

Industrial decision model

The decision model for industrial consumers is simpler than that of residential consumers. For industrial consumers, there are no social dynamics and no questions of ability to pay. All industrial consumers are considered to be within range of the grid and the central question is between grid power use and off-grid self generation. However, while residential consumers are assumed to be unlikely to consider disconnecting from the grid once connected, industrial consumers are assumed to be constantly considering the choice between grid and off-grid power supply.

For simplicity, I assume a homogenous set of industrial consumers. This assumption means that all industrial consumers will be similarly guided by sensitivities to electricity prices, installation costs, and reliability. It assumes that they have the same set of options available for off-grid self-generation and they are have equal access to financing and technical capabilities.

As with the residential decision model, there are specific insights from the ethnographic study which guided the development of the industrial decision model. The most important is the high degree of sensitivity to the unreliability of the grid. Another insight was the potential for industrial consumers to switch multiple times between options. Industrial consumers are also likely to split their consumption between several sources, for example using both grid and off-grid hydropower at a single site, which led to the choice of modeling industrial consumers as units of energy instead of firms. By modeling industrial energy consumption this way, there is no assumption that each firm uses only one source of energy.

Industrial conditional logit function

The allocation of consumer market share is determined through a utility function, based on capital cost, operating cost, reliability, and backlog.

$$U_{ij} = f_j(Capex_i,\ Unit\ price_i,\ Reliability_i)$$

Where:

$$i = Options[Grid,\ Off\text{-}grid\ Diesel,\ Off\text{-}grid\ Hydropower, Off\text{-}grid\ Renewables]$$

$$j = Attributes[Capex,\ Unit\ Price,\ Reliability]$$

As with the residential model, the Expected values are smoothed according to a perception delay.

$$Expected\ value_{ij} = SMOOTH\left(Value_{ij}, Perception\ delay_j\right)$$

The Utility is then determined by multiplying the Expected value (divided by a reference value for scaling) by the Sensitivity of the customer to each attribute.

$$U_{ij} = \frac{Expected\ value_{ij}}{\mathrm{Re}\,ference\ value_j} * Sensitivity_j$$

The Attractiveness of the choices is the exponent of the utility:

$$A_{ij} = \exp^{U_{ij}} = \exp^{\frac{Expected\ value_{ij}}{\mathrm{Re}\,ference\ value_j} * Sensitivity_j}$$

In the Industrial case there is no distinction between urban and rural. Attractiveness of each option is simply divided by the Sum of Attractiveness.

$$Indicated\ share = \frac{A_{ij}}{\sum A_{ij}}$$

The output from this component is the indicated market share for each of the Options, based on the Attributes selected. The market share is presented as a percent from 0 to 1 and the sum of all market shares must equal 1. These market shares are used to determine the allocation of industrial customers.

Allocation of industrial customers

There are two stocks in this component of the model: One stock is the grid generated units and the second is the off-grid generated units, which is indexed for diesel self-generated units, hydropower self-generated units, and other renewable self-generated units. There is flow in both directions between each of the options. There is additional inflow into the stocks through industrial growth. These units are also allocated according to the indicated market share.

The number of units consumed by the industrial sector is assumed to grow according to the predicted value from economic forecasting (KPLC 2000). There is no assumed feedback between the development of the electric power system and the economy. This is taken as an assumption based on Wolde-Rufael (2006), which used regression analysis to determine causality between economic growth and electricity consumption. The results showed that causality cannot be proven (and in some cases there was reverse causality). The reason stated for the surprising result is that with the low penetration of electricity, it is not a significant contributor to economic development. There is likely a threshold point, after which electricity will have an impact. Determining this threshold would be an interesting expansion of this work, which could be added into the model in the future.

Every year a fraction (10%) of the Grid and Off-grid industrial consumers consider shifting to another electricity source. The group considering shifting makes a decision based on the indicated market shares from the logit function. The Table 7 summarizes the potential switches.

Sinks (j): Sources (i):	Grid	Off-grid Diesel	Off-grid Hydropower	Off-grid Renewable
Grid	-	X	X	X
Off-grid Diesel	X	-	X	X
Off-grid Hydro	X	X	-	X
Off-grid Renewable	X	X	X	-

Table 7: Possible shifts in power system consumer choices

For example, of the Grid kilowatt-hours, 10% of the customers will consider switching. If the indicated market shares are all 0.25, then 25% of those units will stay with the grid and 25% will go to each of the other options. Figure 12 shows the structure of the industrial allocation of units. The stocks are the units consumed from grid and off-grid sources and the flows are the shift in units demanded from one source to another.

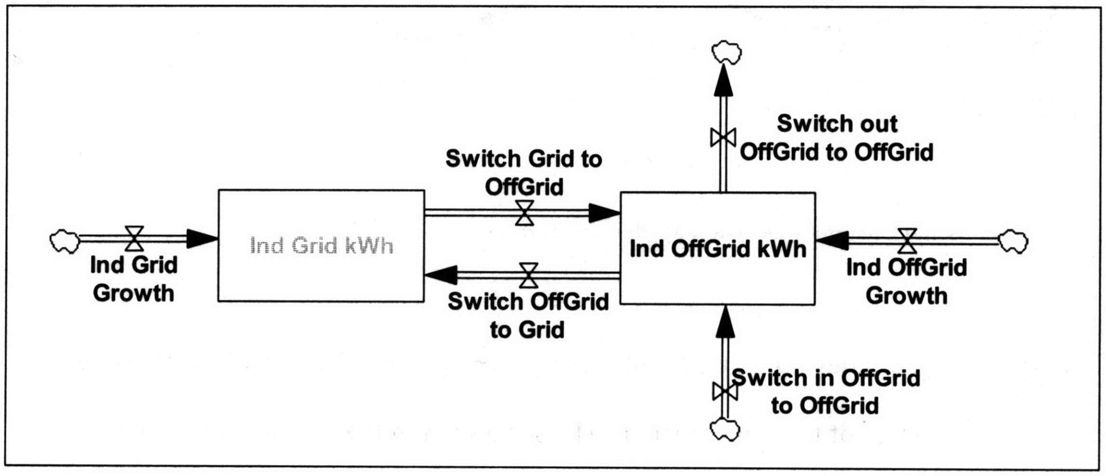

Figure 12: Basic structure of industrial units allocation

Summary of Industrial Decision Model

The Industrial Decision Model has two components: the Industrial Logit Component and the Industrial Allocation Component. The Logit function receives information on Reliability, Cost, and Price from the Financial and Technical Models and determines the Indicated Market Share for each of the electrification options, which is passed to the Allocation Component. The Allocation Component keeps track of the industrial consumers connected to each grid or off-grid power source, as well as load shedding, if needed. From the Allocation Component, the number of grid units consumed is passed to the Financial Model, where it is used to calculate Revenue to the power company. The number of grid units is also passed to the Resource Depletion component of the Financial Model. These relationships are summarized in Figure 13.

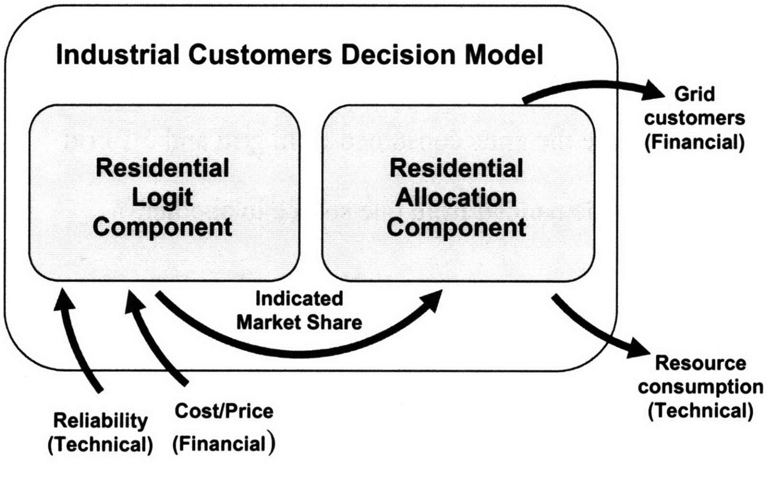

Figure 13: Industrial Customer Decision Model structure

The residential and industrial components are part of the larger Decision Model and both groups are customers of the same system. The separation of the structures indicates both the difference in off-grid options and the difference in decision-making behavior. This difference in customer behavior was one of the insights initially identified in the ethnographic portion of the work, which came to light more clearly through the modeling process. Further discussion of modeling insights can be found in a later section.

Financial elements

The Financial Model has two primary components, Costs and Pricing and Power Company Cash Flow. The Costs and Pricing elements are used to calculate the capital costs and operating (per unit) prices for Grid and Off-grid power. Particularly for off-grid pricing, there is a distinction between the systems that would be purchased by Industrial users and Residential users. The Power Company Cash Flow component is used to calculate the revenue to the power company generated through grid unit sales, which is then used to determine liquidity and the potential to invest in new infrastructure.

The grounded theory work in Kenya revealed the types of systems considered by industrial and residential users, which were used as options in the model. In addition, many of the costing figures used were taken from planning documents obtained from Kenya Power and Lighting Company during the fieldwork. The interviews and research in country also revealed some details of the relationship between KenGen and KPLC. Although KenGen is not a fully privatized generating company, most planning for generation expansion is done by KPLC. The two companies are regulated by the Electricity Regulatory Board of Kenya, but also work together to a certain extent. For example, KPLC was initially paying a reduced rate for electricity units in order to increase cash flow and solvency. Both companies are represented in the model, but their relationship is simplified. KPLC pays a per unit cost for units generated, but it is indiscriminate as to whether they are generated by KenGen or an independent power producer. This cost is deducted from KPLC's revenue stream as an operating expense. For planning purposes, the growth in demand is met by added generating capacity, but it is not specified whether the power comes from KenGen or an IPP.

Several of the price components are exogenously determined since changes in the Kenyan market will not affect them. Oil and photovoltaics prices are determined by the world market prices. In the case of oil, this is based on projected prices from EIA estimates. For photovoltaics, it is assumed that prices will follow the world market learning curve, which sees a reduction in price as the volume of production increases.

Grid price

The final grid indicated electricity price is the sum of the marginal costs:

$$Price = Energy\ MC + Capacity\ MC + Customer\ MC$$

The price is adjusted to charge a higher rate to residential consumers than to industrial consumers. This ratio was set to 0.85, which was determined through calibration to real values. Most price elements were determined using estimates from Kenya Power and Lighting Company records (Kenya Power and Lighting Company 2005).

Marginal energy costs are set at $0.001/kWh for Hydropower and Geothermal sources, and $.005/kWh for Thermal generation, based on the estimate from the KPLC Least Cost Development Plan (2005a). This figure was converted to KSh/kWh using the Real Exchange Rate variable. The total marginal energy costs are calculated by taking the weighted average according to the percent of capacity of each source. Similarly, Marginal capacity costs are calculated by taking the weighted average of the marginal capacity costs of each of the generation source options, also estimated by KPLC in the Least Cost Development Plan. These costs are estimated as $30/kW for Geothermal capacity, $12/kW for Hydropower capacity, $0/kW for imports, and $25/kW for Thermal capacity.

The percent of generation from each source is assumed to be proportional to the generation mix. Kenya does not have the economic dispatch or spot pricing system found in the US power market. The majority of power generation is considered baseload. In the generation capacity portion of the Technical Model, the added capacity is indexed according to source. The percent from each source is therefore the installed capacity of that source over the total capacity.

In addition to the cost of generation, there are two surcharges passed directly to the consumer: fuel and foreign exchange charges. The fuel surcharge is to account for changes in world oil prices and the foreign exchange charges are to account for fluctuations in the Kenyan Shilling compared to more stable currencies. The former has a significant impact on the unit cost of electricity, however the latter has a minimal impact. For simplicity, the foreign exchange element could probably be eliminated from the model; however, it is included here for completeness[22].

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[22] At the time of writing, there had been little recent fluctuations in the exchange rate. However, due to the recent declining value of the dollar and the instability in Kenya as a result of the 2007 election, this could be a more significant factor in the future.

The fuel surcharge is calculated by:

$$Fuel = \frac{1}{1 - Losses} * \left(\frac{Diesel\Pr ice * SFC * TotalEPP}{TotalGrid} - Base \right)$$

Where Losses are estimated at 15%[23], Diesel Price is the price of diesel in Kenya, SFC equals the specific fuel consumption by power plants in the system, Total EPP is the number of units from thermal sources, Total Grid is the total number of units generated from all sources, and Base is the base fuel price in Kenya. Documentation of these variables can be found in the Appendix.

The calculation for the Forex surcharge also comes directly from the KPLC Schedule of Rates (2005).

$$Forex = \frac{(ZF + Y)}{(1 - Losses)}$$

In addition to the surcharges, there are two fixed taxes levied on electricity prices. There is a standing value added tax of 18% on all electricity energy consumed with an exemption of first 200 units under domestic consumption. The Electricity Regulatory Board charges an additional 3 cents per kWh to help fund their operations. For this model it is converted to KSh, 0.03 KSh/kWh.

The total indicated grid price is then multiplied by a factor which biases the price in favor of industrial consumers. This is a common practice to have industrial electricity costs lower than residential prices. This bias is approximated based on historical data

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[23] This is the estimation for losses is the value in KPLC's estimation and is not varied.

comparing the residential and industrial prices and is estimated as 1.2. Although the indicated price is used to set electricity prices, the ERB only reviews prices approximately every five years[24]. Therefore, there is a variable for delay for regulatory price setting. Using current data, the price charged is very close to the LRMC price according to KPLC's price setting calculation, largely because of the high fuel surcharge price, which is levied after the ERB price setting.

Off-grid industrial

There are two financial components related to the cost of off-grid industrial options, capital cost and price per unit generated. The latter has a further two elements, the fixed cost of capital and the operating cost. In order to standardize the comparison, a fixed generator size of 2 MW was assumed. This is related to the assumption that the model focuses on a representative agent, who is considered an "average" decision-maker for the sample.

The capital cost is the total installed cost of a 2 MW power system, either a diesel generator, a hydropower scheme, or a photovoltaic system. The first two are assumed to not need storage capacity, while the PV system requires a battery bank. In all cases, the fixed cost of operation is the cost of maintenance of the generator, while the operating cost is the cost of fuel inputs to the system. Table 8 summarizes the assumed values for the model[25]. (Source: KPLC 2005, World Bank 2005).

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[24] The ERB has only been in existence since 1997 so it is unclear how often prices will be adjusted in the future

[25] For PV capital cost, value given is initial cost. The price of PV system is assumed to drop based on learning curve. Hydropower cost is also the base price, the price will go up based on scarcity of resources.

Cost : Source:	Capital cost ($/kW)	Operating cost ($/kWh)
Diesel generator	620	0.035 + fuel
Hydropower generator	1800	0.05
PV System	4265	0.07

Table 8: Costs for industrial off-grid generation

The fuel cost for diesel generation is based on the projected oil price, converted to Kenya prices, and the rate of consumption per kWh.

Off-grid residential

Off-grid residential capital costs and unit costs are based on purchasing a diesel or photovoltaic home power system. The estimated capacity need per household connected to the grid is 250 W; however, off-grid PV users will most likely purchase a smaller system. To fix system sizes across diesel generators, PV systems, and the grid is unrealistic. For this reason, I assume the goal is to have an electricity connection, regardless of capacity. Then the system size can be fixed to the average size for that option. The PV system was sized as a 50W system, which fits with the findings of both the fieldwork from this research and market studies in the country (Kammen 2005). Diesel generator customers are likely to try to purchase the smallest system possible, however 300W was the smallest observed system in Kenya. Therefore, diesel generator prices are based on purchase of a 300W system. Table 9 shows the assumptions used in calculating cost of connection for residential consumers[26].

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[26] PV price will drop according to PV learning curve. Grid connection price is promotional price for Umeme pa Moja program.

Attribute: Option:	System size (W)	System cost (KSh/system)
Grid connection	250	35,000
PV system	50	32,870
Diesel generator	300	13,500

Table 9: System size and cost for residential options

Using different generator capacities may seem to be comparing apples to oranges, but the incremental quality of life improvement that comes from moving from 50W capacity to 300W capacity is significantly smaller than the improvement from no connection to any connection. For this reason, the systems are estimated as the average system that will take a consumer from no power to power for each technology option.

Power company cash flow

The power company cash flow is the difference between the revenue coming in to the company through electricity sales and the expenses due to generation purchases, capacity maintenance, taxes, corruption and debt servicing. There is an additional outflow from the grid units in both the residential and industrial case. This is the loss of units due to load shedding. In the Technical Model, the potential energy capacity of the system is estimated from the power capacity. If there is insufficient capacity to meet demand, the units cannot be used by either industrial or residential consumers. The calculation of load shedding is discussed in greater detail in the Technical Model description.

In the power company cash flow, there is an intermediary in this process that is not modeled. I assume money goes directly from KPLC to investment in grid, since they appear to be making planning decision. The fact that KPLC publishes the Least Cost Development Plan for generation shows their influence in the system. If the system becomes truly unbundled this will need to be shifted in the model to represent the autonomous generation planning.

Revenue is calculated by taking the total residential and industrial units sales for the year and multiplying by the respective prices charged. The revenue that actually flows into the company is the product of the percent of meters read and the percent of bills collected.

*PowerCo % Meters read * PowerCo % Bills Collected = PowerCo Performance*

PowerCo Performance(PowerCo Rev from Ind+ PowerCo Rev from Res) =*
PowerCo Revenue Total

Both performance measures are initially set to 85% and there is no feedback to change this value. This issue is revisited in Chapter 5 as one of the scenarios explored is the addition of feedback where KPLC responds to customer demands for increased connection capacity and better service.

On the expense side of the balance sheet, the company then must pay the generating companies for the energy distributed. The current contract for power purchases is set at 1.76 KSh/kWh[27]. Although the power company must purchase energy from the generation companies, they own the transmission and distribution system and must

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[27] The bulk power rate has been the subject of debate in Kenya. Although set at 1.76 KSh/kWh at the time of beginning fieldwork, this rate was intentionally low to help KPLC become solvent. However, KenGen argued that the rate was supposed to be temporary and needed to return to the agreed rate of 2.36 KSh/kWh out of respect for their shareholders. Since the rate was still under debate, the rate was left at 1.76 KSh/kWh, however this should be re-addressed in future work with the model.

maintain these assets. There is a fixed charge for transmission and substation maintenance, estimated at 2% of the purchase price.

There are also several taxes levied on the revenue stream. First, there is the official government tax, set at 20% (approximated from KPLC annual reporting). An additional charge of 5% of income from unit sales is used to pay for Rural Electrification Programme (REP). There is also an estimate of funds which are misallocated during operations. This "corruption tax" is one of the ways corruption is handled in the model. Finally, the company payroll is represented as a tax. At this point KPLC operates very inefficiently so the rate is set at 10% of the gross income.

In summary:

PowerCo Cash Flow =
PowerCo Revenue Total – [(PowerCo Debt Repayment+Interest on Debt)+PowerCo Cap Maintenance+PowerCo Payroll+PowerCo Corruption Tax+PowerCo REP Levy+PowerCo Taxes]

The effect of the power company internal cash flow is felt in the acquisition of new capacity, both generation and transmission. Low or negative cash flow for the power company means that they will need to seek external funding. It is assumed that this funding becomes available, either through international lending or development aid, but this increases debt. The debt repayment then becomes another deduction from the cash flow. This cycle of debt very quickly creates a vicious cycle as servicing the debt further hinders the company's ability to become solvent. There is a second flow out of debt, which estimates the money paid either as international aid or as a government bailout. It is very likely this scenario will be used, given the close cooperation of the Power Company, generating companies, and government. Although this dynamic is seen in industrialized countries, for example the US government has assisted air transport companies in the interest of the larger economy, it is even more likely to happen in a developing country given the overall instability of infrastructure systems. Early model runs showed that a debt forgiveness of at least 20% was needed to make KPLC solvent for future development of the grid. For the base model run, the bailout was set to 25%. This point is discussed in the policy implications from the base case in Chapter 4.

To estimate the effect of cash flow on capital investments, the cash in is compared to the cash required.

PowerCo Liquidity = PowerCo Cash Flow/PowerCo Cost of New Construction

This measure of liquidity is used to determine the effect on capital orders and acquisitions. The effect on ordering is more quickly felt than the effect on acquisition since it is assumed the company will be more likely to cut costs choosing not to order capacity rather than choosing to stop building capital already in the pipeline. It is further assumed that the same effect from liquidity will increases cancellations of capacity on order. Figure 14 shows the functions used to approximate the effect on ordering and acquisition of capital.

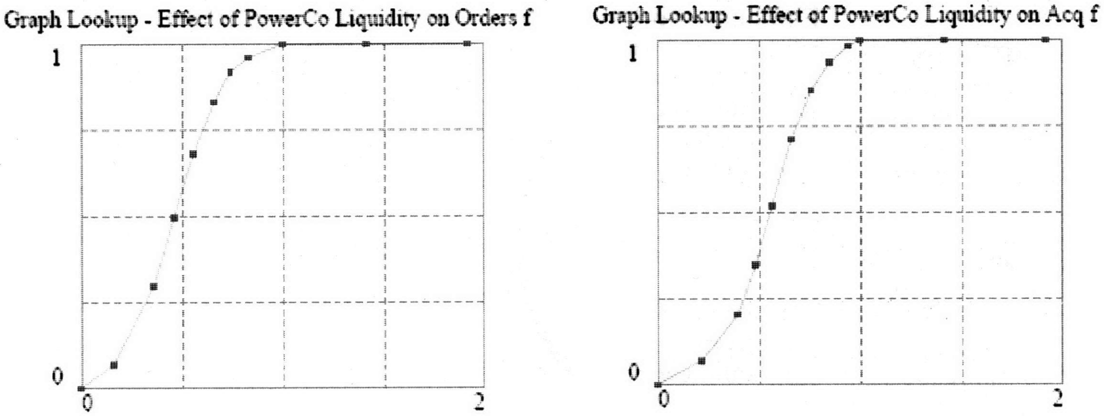

Figure 14: Lookup functions for the effect of power company liquidity on Capital Orders (left) and Acquisitions (right)

The slope of the function indicates that the company will limit their ordering or acquisitions if PowerCo Liquidity < 1. The effect is greater for ordering because it is assumed that the company will be more likely to reduce ordering before reducing acquisitions of capital already on order.

Summary of Financial Model

The Financial Model focuses on the unit prices and capital costs to the consumers and the cash flows to the power company. Figure 15 shows the basic inputs and outputs for the Financial Model.

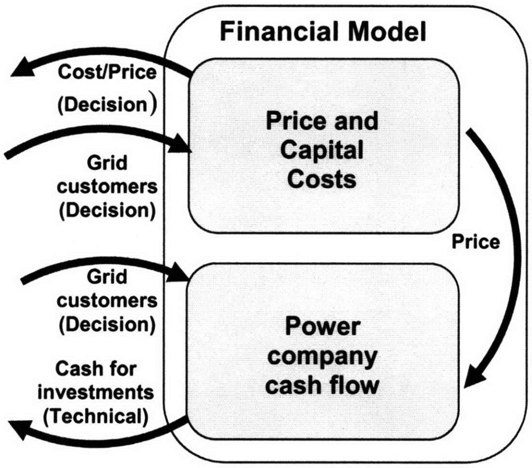

Figure 15: Financial Model structure

Technical capacity elements

The model of capital stock also follows a basic model from Sterman (2000). The production capacity structure models the stock of capacity on order and in use, based on the order rate, acquisition rate, and discard rate. These rates are subject to adjustment and acquisition delays, with the desired supply of capacity driven by the forecasted power demand.

Resource depletion

The primary fuel supplies for generation are: oil, solar, imports, geothermal, and hydropower. The first three resources are considered inexhaustible within Kenya. This assumes no disruption of supply in oil and no ban on imports from Uganda and Tanzania, the two potential sources of electricity for Kenya[28]. While the supply of solar energy is clearly inexhaustible, the assumption includes the supply of PV technology into Kenya.

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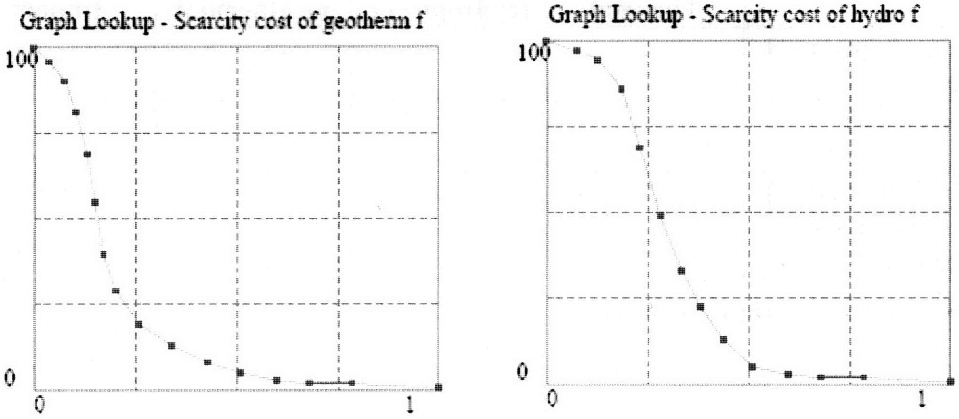
[28] Under an old agreement, Kenya already imports 50 MW from Uganda. This assumption is used because it is part of the development plan as stated by KPLC, however it assumes that Uganda and Tanzania will have sufficient supply in the future to sell a portion of it to Kenya. Given the dual power crises in the two countries in the past two years, this assumption needs to be examined further in the future.

It assumes the PV panels and the complementary equipment will be readily available in Kenya for the lifetime of the model projection. Geothermal and hydropower resources are considered finite resources in terms of capacity. While both are renewable resources in terms of energy, the total power capacity is limited.

As the inexpensive sources of geothermal and hydropower energy are exploited, each additional unit of capacity becomes more expensive. To represent this cost of extraction in the model, there are two cost functions which increase a cost factor as resource goes to 0. The slopes of these cost factors are unknown so they are approximated in the model (Figure 16). The x-axis shows the percent of the resource remaining and the y-axis shows the cost factor.


Graph Lookup - Scarcity cost of geotherm f

Graph Lookup - Scarcity cost of hydro f

Figure 16: Lookup functions used to estimate added cost of scarcity for exhaustible resources

The slopes for the scarcity cost curves are based on the estimates of financially viable resources (IEA 2008, BCSD 2003). Both are assumed to become more expensive as resources are depleted.

Generation capacity

The Generation Capacity Model based on the standard capital stock management structure (Sterman 2000). It is indexed according to type of company and type of generation.

$$Generation\,capacity_{ij} = \int(Acquisition\,rate - Discard\,rate, Generation\,capital_{t_0})$$

Where:

$$i = \text{Generation source[Thermal, Hydropower, Geothermal, Import]}$$

The Acquisition rates and Discard rates for the generation options are based on expected installation and lifetime of plants, respectively. Table 10 summarizes the assumptions used in the model (World Bank 2005, KPLC 2005).

	Thermal	Hydropower	Geothermal	Import
Supply Line Adjustment Time (Year)	5	5	5	5
Acquisition Delay (Year)	1	5	5	2
Life of Capacity (Years)	25	50	25	50
Capacity Adjustment Time (Year)	5	5	5	5

Table 10: Summary of capacity assumptions

Using these inputs:

$$Discard\,rate_j = {Generation\,capacity_j}\Big/{Average\,life\,of\,capacity_j}$$

$$Acquisition\,rate_j = DELAY3(Order\,rate_j, Capacity\,Acquisition\,Delay_j)$$

There is an additional outflow from the Capacity on Order stock due to cancellations. It is assumed that a fraction of orders will be canceled for a variety of reasons, such as changes in planning or permitting issues.

Generation capacity planning

The price of grid electricity is, in part, determined by the number of units generated by thermal sources and the mix of generation sources. Therefore, the model must add capacity so that the generation mix reflects the realistic growth in the system. To accomplish this, I used a market share model very similar to the customer allocation structure (see section on Residential or Industrial conditional logit function). The generation source shares are based on marginal cost of capacity and expected price per unit. All figures used in this component are from the Least Cost Development Plan in order to reflect the values used in Kenya's own planning. However, my model does not replicate exactly the LCDP because of the low projection of oil price used in the Kenya model (see discussion in Chapter 4).

Transmission and distribution capacity

The second and third components model the capacity of KPLC's transmission system. These components are measured as miles of transmission lines and transmission level substation capacity (in KVA). These metrics were selected as a baseline measure of the quality of supply and the carrying capacity and management capability of the system (assumption is discussed in greater detail in following section on reliability).

The structure of the lines and substations stock management structure is the same as for generation capacity. There is no indexing for these cases, because the generation source does not matter once the power is on the transmission system, but there is still a reduction in capacity ordering and acquisition based on the liquidity of the company.

Reliability component

Reliability in the systems is determined by the expected likelihood of outage on the system. The reliability component of the model compares the actual transmission line, number of substations, and generation capacity with the quantity required for the given level of consumption. Based on the ratio of required to actual, the reliability of the system goes up or down. The reserve margin is set at 15%. If the ratio of actual to required capacity is 1.15 or greater, then the reliability is close to 1. As the ratio falls below 1.15 the probability of failure increases and the reliability goes down (Figure 17).

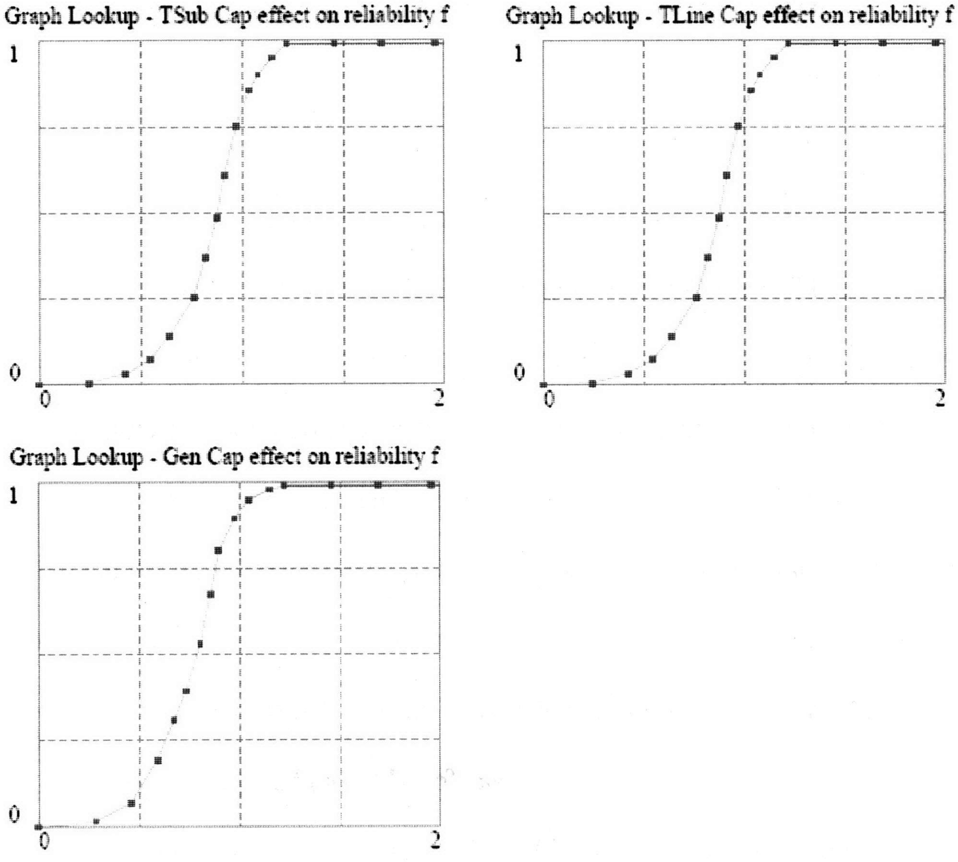


Figure 17: Reliability curves used to approximate quality of grid service due to capacity

The effect on overall reliability is calculated by using which is the probability of no failure.

$$P(\overline{F}) = (1 - P(GenF)) * (1 - P(TranF)) * (1 - P(DistF))$$

This probability of no failure is passed to the Decision Model and is used to influence customer decision-making when considering grid and off-grid options. By comparison, off-grid options are considered 95% reliable ($P(\overline{F}) = .95$). The model is not technically detailed enough for this to be considered a prediction of failures on the system. Rather, it is a relative scale of reliability in the system, used for understanding changes over time and comparative quality.

The required capacity was based on transmission lines and substations. These are lines rated at 132 kV or 220 kV and substations rated at 132/220 kV, 220/132 kV, 220/66 kV, 132/66 kV, and 132/33 kV. This represents the lines coming out of the generating plants and the first step down onto the distribution system. After this point, the distribution complexity becomes too great to be useful in the model. The carrying capacity of the transmission system is taken as a measure of the high level robustness of the system, with the understanding that more isolated failures will occur due to overcapacity and faults on the distribution lines. According to Baughman and Bottaro (1976) the required transmission length is 0.1436 miles/GWh. This was found through regression analysis. The required substation capacity is 523.2 KVA/GWh*year for industrial supply.

If generation capacity is insufficient, it has another direct effect on the system in the form of load shedding. The excess demand for power is not met and cannot be included in the revenue stream of the power company. In the reliability component of the Technical Model the number of units over system capacity is calculated. This figure is then split into industrial and residential units that need to be cut off, according to the current shares of the market. The units are subtracted from the annual energy demand, used in calculating revenue.

Demand forecast

The growth in capacity demand is forecasted using the TREND function as described by Sterman (2000). This function estimates the fractional growth rate of a variable, based on the difference between the perceived present condition of the variable compared to a reference condition over a set time horizon. Figure 18 shows the basic structure of this function.

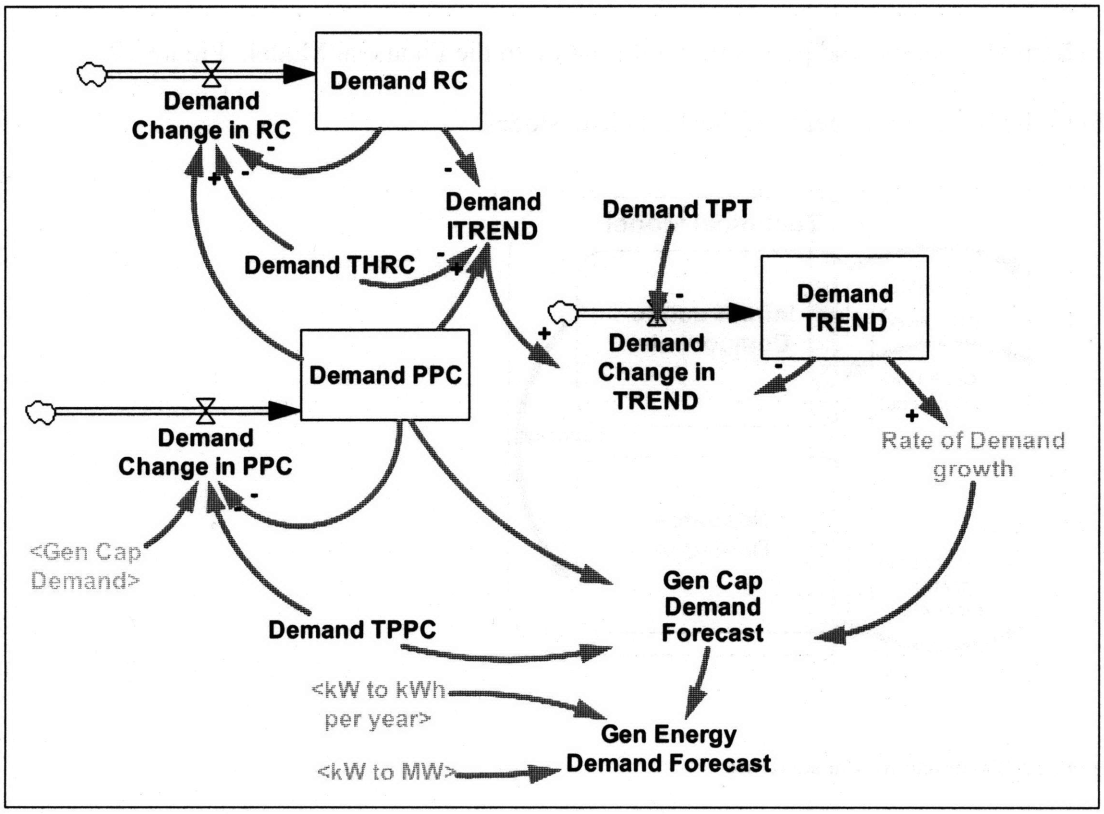


Figure 18: Structure of TREND component used to forecast demand growth

For this model, the perceived present condition was initialized at the kWh demand for the year 1995 and the initial growth rate was set at 3%, seen over 5 years. For simplicity, I assume the average mix for the year because they are using most of their capacity. As a result, sales ratios are the same as capacity ratios. This assumption was verified visually from planning documents (KPLC 2005, 2006).

Summary of Technical Model

The Technical Model keeps track of infrastructure capacity and compares that capacity with demand to estimate reliability of the grid system, which it passes to the Decision Model. It also keeps track of resource consumption, in the case of hydropower and geothermal capacity, and passes that information to the Financial Model. Figure 19 shows the basic components of the Technical Model.

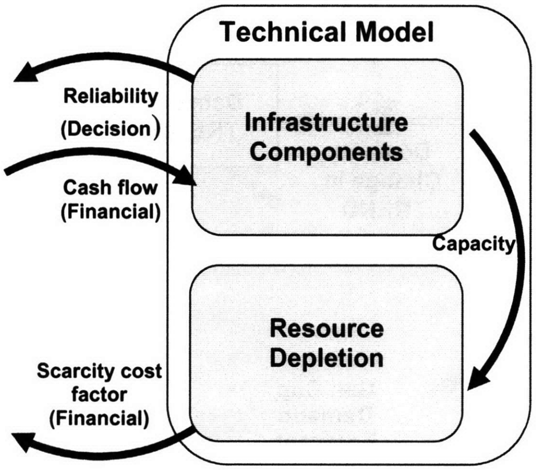


Figure 19: Technical Model structure

In the initial development of the model, the components were tested independently, then linked through the variables shown in Figure 11-Figure 19.

Basic model testing

This section explores some of the dynamics of the model through the calibration and testing procedure. All examples are from the base case run of the model. Scenarios for future developments are explored in the next chapter.

Calibration

The model was calibrated to fit historical data on price (KSh/kWh), units sales (kWh/year), generation capacity (MW), transmission line capacity (miles), transmission capacity (KVA), and generation demand (MW). Figure 20-Figure 26 show the graphs used for visual inspection of fit and Table 11 summarizes the Theil statistics used to test variable calibration (Sterman 1984).

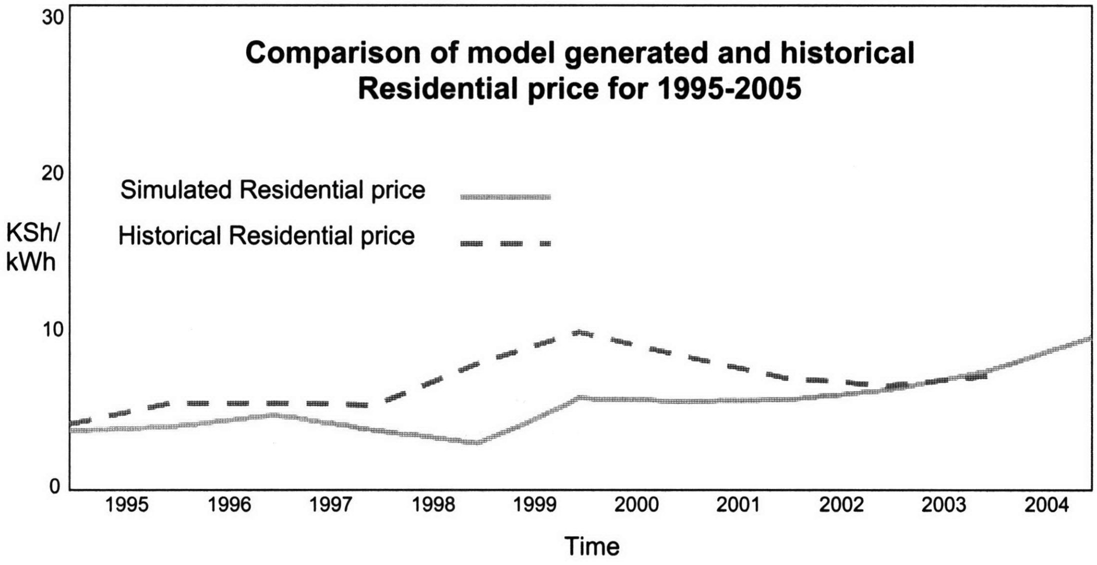


Figure 20: Comparison of model generated and historical residential price for 1995-2005

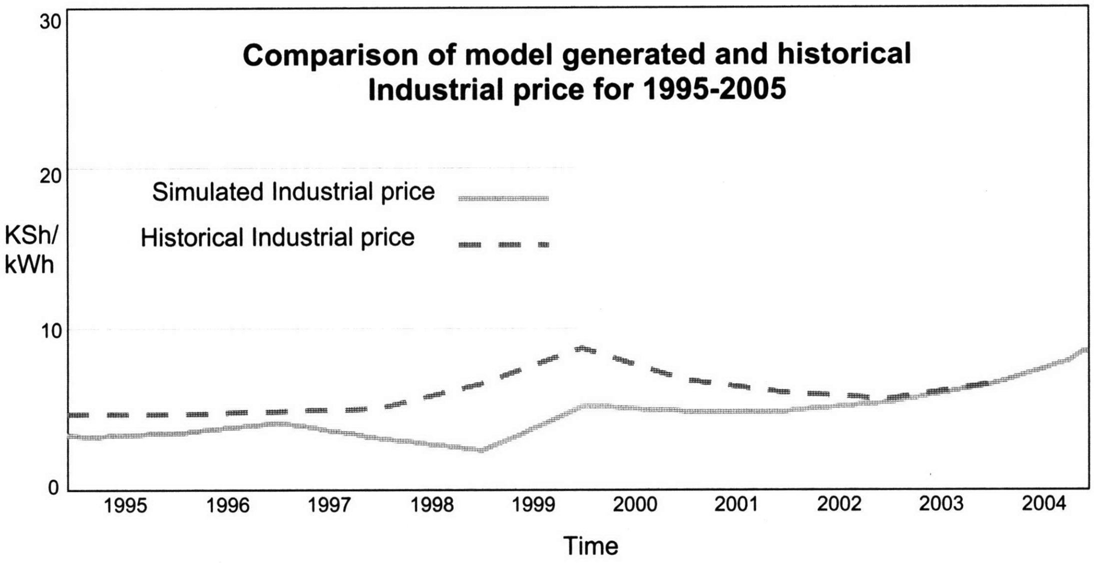


Figure 21: Comparison of model generated and historical industrial price for 1995-2005

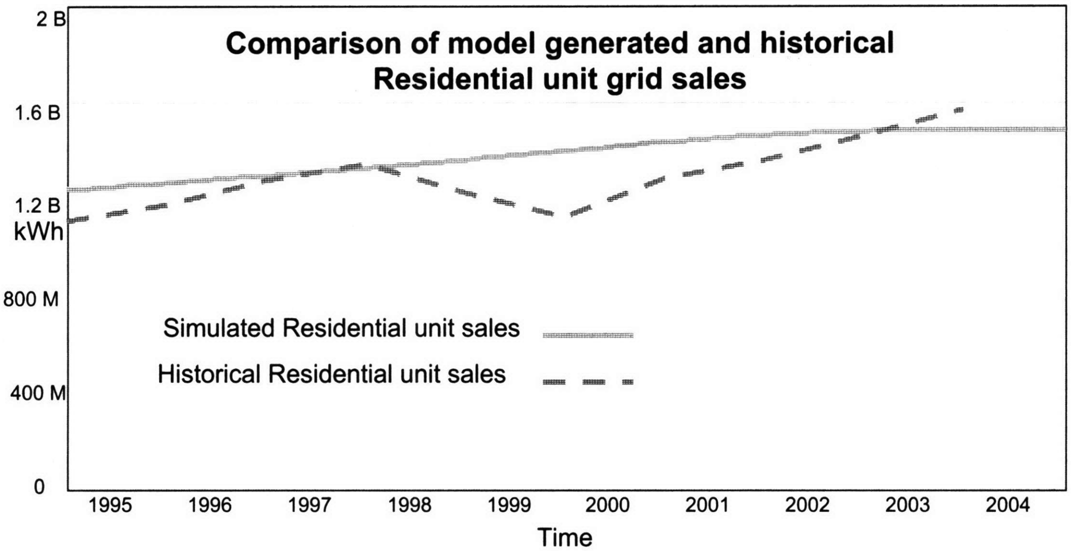


Figure 22: Comparison of model generated and historical residential unit grid sales

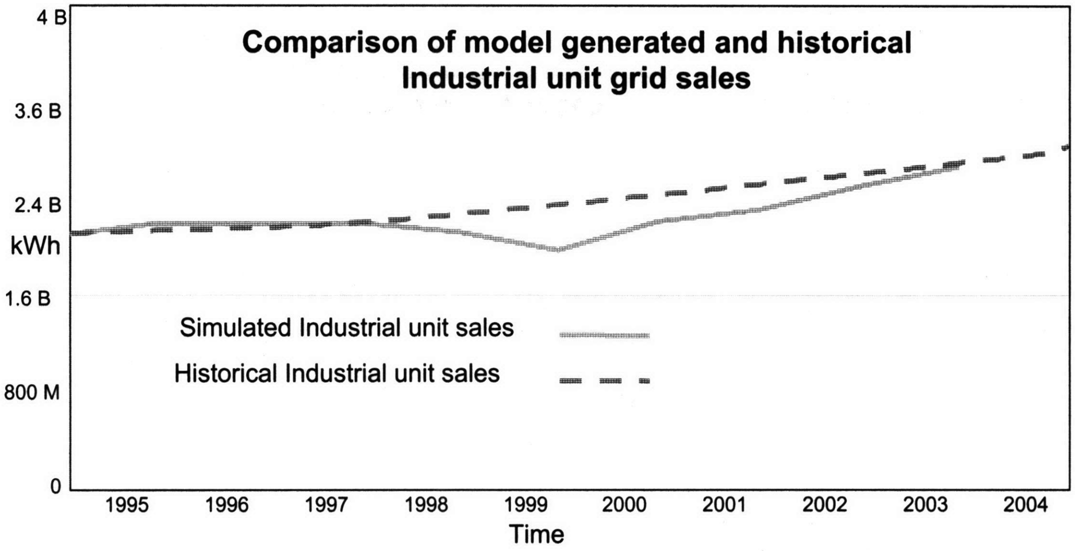


Figure 23: Comparison of model generated and historical Industrial unit grid sales

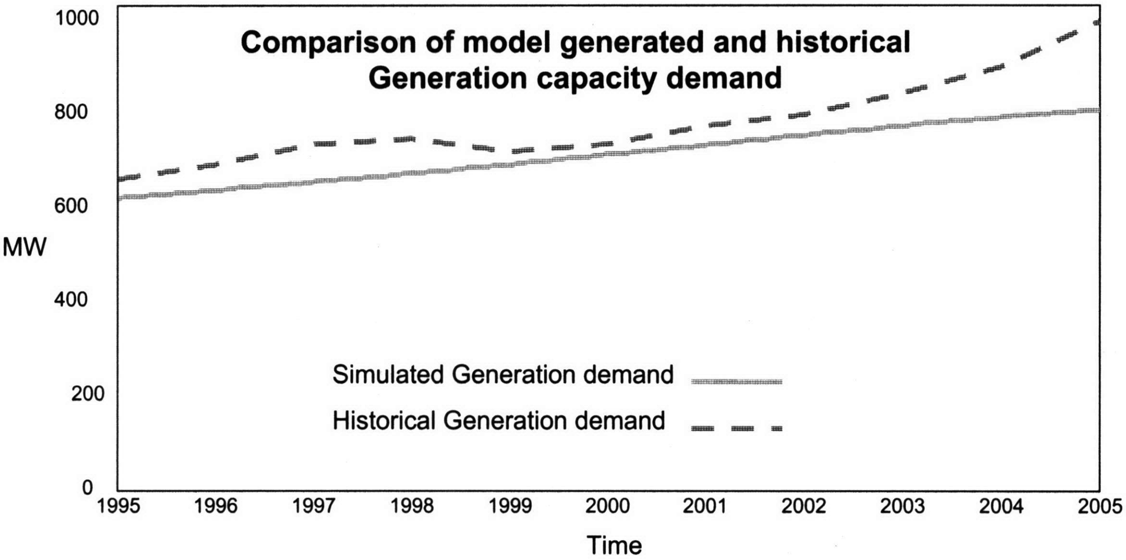


Figure 24: Comparison of model generated and historical generation capacity demand

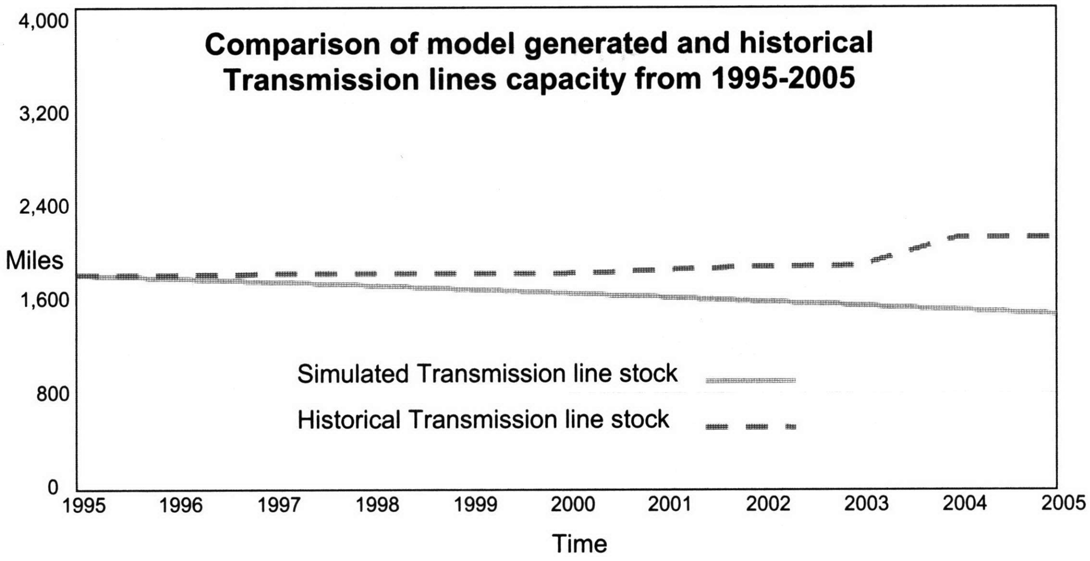


Figure 25: Comparison of model generated and historical transmission line capacity

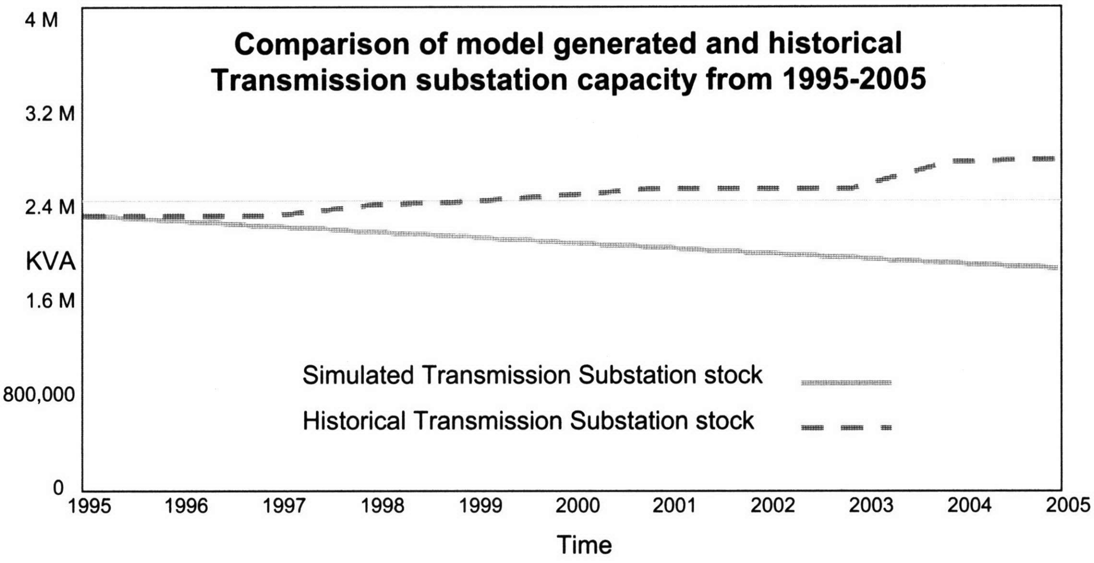


Figure 26: Comparison of model generated and historical transmission substation capacity

Statistic: Variable:	R^2	Variation	Covariation
Residential Grid Price (KSH/kWh)	0.18	1.81	0.61
Industrial Grid Price (kWh/kWh)	0.22	1.19	0.47
Residential Unit Sales (kWh/year)	0.53	13,956.99	7,495.94
Industrial Unit Sales (kWh/year)	0.51	40,174.72	28,388.60
Generation Demand (MW)	0.83	7,526.56	4,899.96
Transmission Line Cap (miles)	0.52	21,997.03	-6,700.75
Transmission Sub Cap (KVA)	0.88	51,045.61	-16,447.22

Table 11: Summary of Theil statistics for calibration of model

The results show that the model fits the basic trends of the power system development, except in the case of transmission and substation capacity. In these cases, even though the fit may not be ideal, I believe the model is simulating the real dynamics. For example, in the simulated cases both transmission line and substation line capacities immediately begin to decline because there is no cash to acquire new capital and some of the capacity is at the end of its lifetime. In reality, the lines were not retired and no capacity was added so the capacity remains roughly constant. The lines are aging, however, and there is more likely to be faults on the transmission system. This is reflected in the reduction in reliability seen in the simulation. Realistically, there was a decline in viable capacity, even though it is not reflected in the reported historical figures.

Greater detail could be added to improve the fit for the calibration variables, however this would likely require an expansion of the model boundary or added complexity, which would detract from the basic relationships. Two examples of this added detail would be the addition of international financing or hydrological disruptions. Although many of the capacity additions are funded by international governments or aid agencies, trying to include these dynamics in the model would add unending layers of complexity and politics. In the model this is handled simply as a bailout or default, which erases the accruing debt to the power company.

Another element that has affected the Kenyan power system in the past decade, the time period of calibration, is the lack of hydropower capacity due to drought. This is an exogenous variable in the system, which is not included in the model. One could argue that a very broad model boundary would include the feedback between the lack of electricity causing an over reliance on biomass, which causes deforestation and worsens drought. It could also be added to the model as an unpredictable shortage with simulated regularity, however, hydropower plays less of a role in the future of power generation in Kenya and adding drought as a variable would weaken the claim that the model is generalizable.

Uncertainty

There is a high degree of uncertainty in a number of the variables used in the model. Rather than omit these values, they were included in the model and were tested to understand how sensitive the outcomes of the model were to changes in these variables.

First, the model was tested for the changes based on some of the basic parameters of the model. This included the attribute sensitivities used in the logit model used to determine market share. Experimenting with the controls of the model showed the model was very sensitive to the price of photovoltaics, the price of oil, and the finances of the power company. As an example, Figure 27 shows the sensitivity of the indicated market share of grid power to changes in the price of PV.

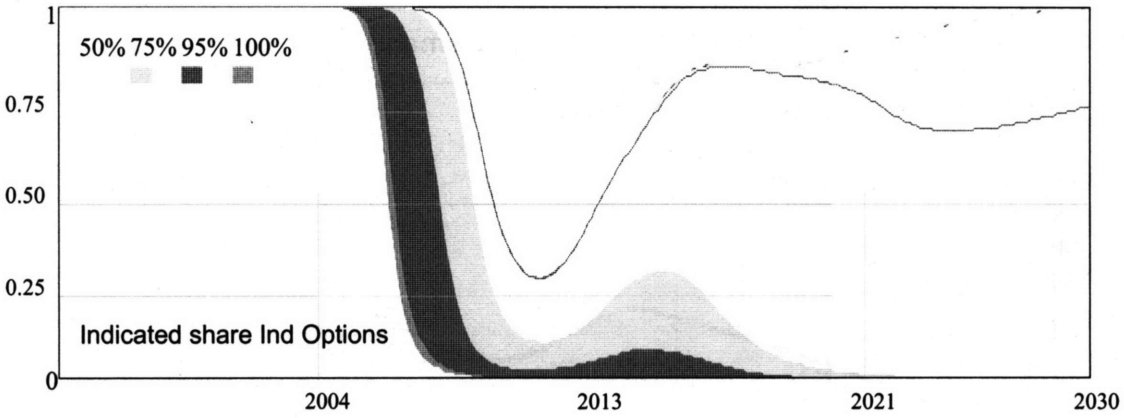


Figure 27: Sensitivity of industrial indicated market share for grid power to changes in PV surcharge

Base results

The base model results show a system where grid energy demand declines for a period, then recovers and continues to grow (Figure 28). This pattern is the result of changes in price, reliability, and finances for the power company.

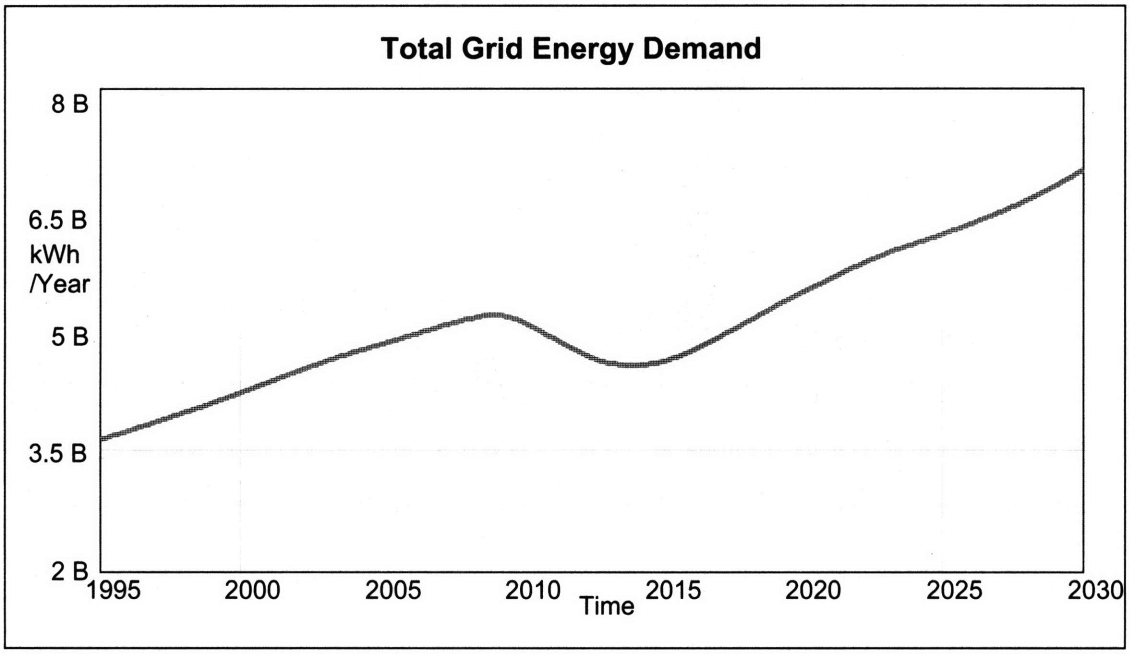


Figure 28: Grid energy demand - Base Case

On the industrial side, grid is the preferable choice in the long term since the lower cost option of hydropower becomes more expensive due to scarcity. For residential consumers, PV will be the dominant choice, particularly as oil costs rise and PV prices fall.

Discussion

The next chapter discusses the insights from running the model, however there were also insights discovered in the modeling process. Some of these insights were not apparent in the grounded theory portion of the research, but only appeared during the detailed study needed to construct the model. Additionally, the modeling process also revealed several areas of expansion for future research.

Insights from the modeling process

The grounded theory research gave many insights into the system development in Kenya, however there were also elements that were not clear until the modeling process. In some cases the modeling process simply allowed for a more careful examination of the dynamics, and in other cases the model revealed feedbacks and relationships that were not obvious from the interviews and prior research.

During the fieldwork it was clear that industrial and residential consumers have different priorities when making decisions about electricity, however, the modeling showed that the two groups are really two separate markets. The two groups at this point represent the dual economies found in many African countries, where the residential consumers are the informal sector and the industrial consumers are the formalized economy. A second insight from the modeling process was the level of detail needed to describe the system and the challenge in representing the system simply. The rough boundary for the model was created in the planning stages and revised during fieldwork. The boundary definition was intended to be relatively small, excluding foreign involvement and world markets, with the rationale that this would keep the model simple and relevant to Kenya. However, the vision of a very small dynamic model with only a few stocks and feedbacks was not able to represent the complexity of the relationships between stakeholders or the operations of the system. This resulted in a large expansion of the model in terms of variables, even without changing the boundary. It also highlighted the number of simplifications that were made, even when additional complexity had been added. The trade-off between trying to take a high level view of the problem, while still making the model both manageable and relevant, should be considered in future models.

A final insight from the process of creating the model is the lack of feedback at certain points in the system. A number of people I've talked have wondered why there is such a substantial unmet need for power connections, which is a good question. Is there a particular challenge with regard to price, supply chain or operations of the power company? KPLC and others in the market are clearly aware that there is unmet need, but they are seemingly not reacting to it. Is this due to bottlenecks like the supply capacity of KPLC and why are they not able to grow to meet demand for connections? These are questions which need more detailed analysis.

The base runs of the model revealed several feedbacks not considered in the development of the model. Two of these feedbacks were balancing loops, which mitigated the potential shift from grid to off-grid power sources. First, I had not initially thought about how depletion of hydropower resources would be a balancing factor in this system. Second, as the reliability goes down and more people more off the grid system, it reduces the traffic on the system and the reliability subsequently improves. In the long-term, this produces an oscillating behavior as capacity expansion lags demand. Similar dynamics are seen in commuter traffic, where if congestion gets too heavy some drivers will choose other options until the congestion is reduced. When the perceived congestion is reduced, some commuters will then switch back to driving, starting the cycle again.

Model expansions

As with any model, there are limitations in the accuracy of representation. The concluding chapter explores some of the options for research building off the model, but there are also some potential expansions in the scope and method of the model. There are several assumptions and modeling choices that could be further explored. For example, as mentioned previously, there is currently no link between economic growth and the development of the power system. This was an assumption based on the literature specific to the African context, however it is assumed to be inaccurate in a more developed setting. If it is expected that Kenya will reach a point where there is a direct correlation between economic growth and electricity consumption, then that relationship should be added to the model. One expansion of the model could be to explore this relationship and attempt to determine the tipping point at which the impact will be seen.

A second assumption in the model is that industrial and residential consumers act as homogenous groups. While the behavior of the two groups independently is quite different, within the groups they are considered as one decision-maker. This assumption was based on the consistency of responses in the interview data and the lack of availability of spatial data. If it were possible to determine each user's spatial relation to the grid and off-grid resources, it would be possible to distinguish between groups. If this were the case then either the model could be further indexed, or it might be more appropriate to then use an agent-based approach. If more detailed spatial data becomes available in the future, that would be a logical expansion of the model.

A final question in the modeling assumptions is the lack of certainty in a number of the assumptions given. In particular, the sensitivities to the power source attributes and the delays in the system are all assumptions. All parameters were based on the information available, but now that the basic structure of the model is built and the context of decision-making is better understood, this might be an area to expand. It would be possible to design a survey of consumers specifically focused on their decision-making thresholds in order to glean their true sensitivity to reliability as compared to price or capital cost.

The purpose of the system dynamics model is to provide a descriptive model of the interaction between electric power customers and the power system in Kenya. Although the next chapter will explore how the model responds to a range of scenarios, the real value is in identifying leverage points and understanding policy implications.

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Chapter 4

Policy options and implications

Introduction

This research was conducted in three parts. The first was a study of the on-the-ground relationship between electricity consumers and the system, the second was building a model to understand the feedback in the system, and the third was using the model to look at policy options in development planning. The base case discussed in the preceding chapter provided some initial insights by identifying potential policy levers in the system. These insights provided the basis for the scenario exploration. The scenarios described are intended to show the potential use of the model, not to make predictions about future policies. The model runs primarily produced new insights into important variables to consider in electrification planning and where changes in policy could have impacts on future development.

Behavior from base case

For the base case, the basic feedback in the system can be seen by looking at the electricity consumption, power company cash flow, capacity growth, reliability, and indicated market shares. These outputs capture reinforcing loop seen in Figure 6 in the preceding chapter.

In the base case run, grid is the best choice for industrial consumers for roughly the first third of the run. Around 2008 in the model, oil prices start to rise, making grid power more expensive, and the lack of infrastructure additions brings on a decline in reliability. These forces make hydropower more attractive for a period, until the scarcity of hydropower drives up its price as well. At that point, grid begins to dominate, but is challenged later by renewables. In the final years of the model run, grid again begins to recover because of the improved reliability of the grid and because the model assumes a floor in the decline in PV prices. However, if the PV prices continued to fall then the role of PV in the system would continue to grow.

These trends are seen in the number of units demanded from each source. For a period, preference for the off-grid options takes a share of the market away from grid, but the grid recovers and remains the primary supplier for industrial consumers (Figure 29).

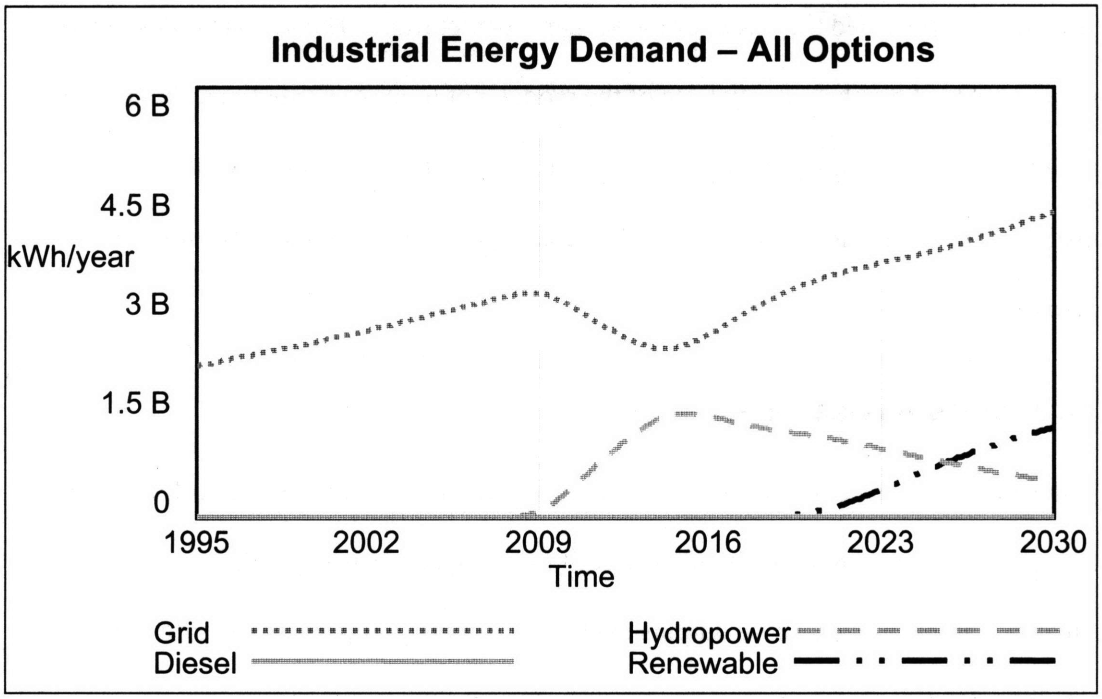


Figure 29: Industrial energy demand by source - Base case

On the residential side, the grid loses market share to renewables, PV in this case, in both the rural and urban markets (Figure 30, Figure 31). For both residential groups, declining reliability and backlog in grid connections will make renewables a better option for a period. As the reliability begins to grow and the backlog diminishes (since there is less demand), grid begins to recover as an option for a portion of the market. However, around 2012 the price of renewables falls below grid due to a decline in the price per watt of photovoltaics and an increase in oil costs. This results in renewables again becoming the dominant option in the market.

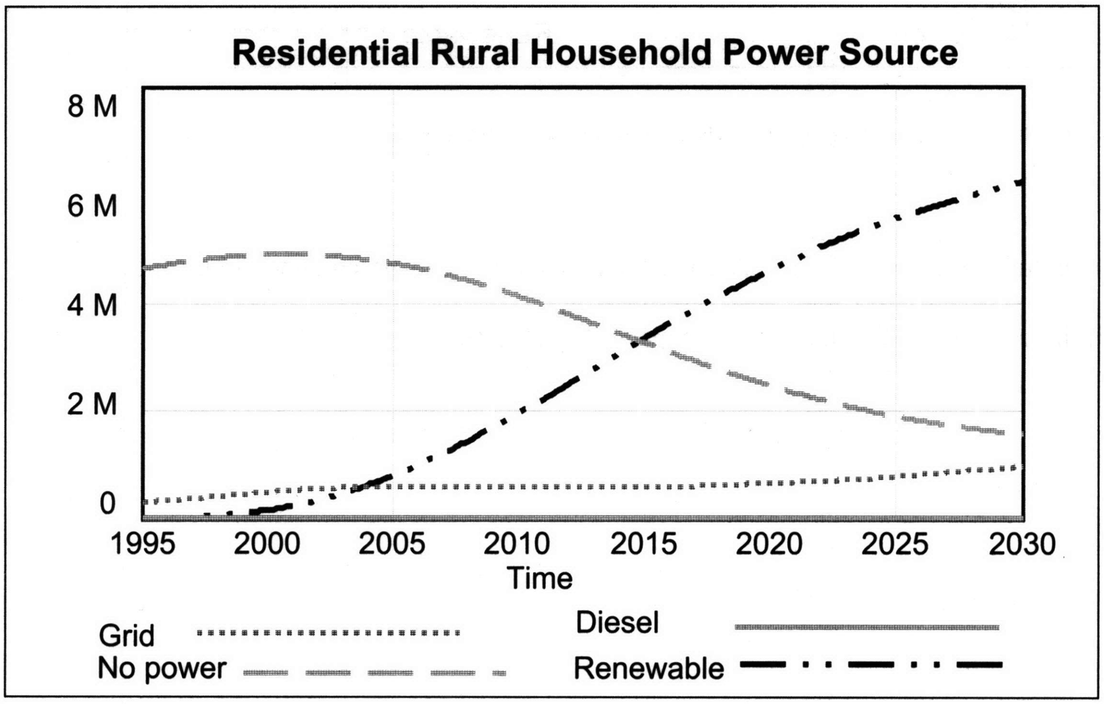


Figure 30: Rural residential power source - Base Case

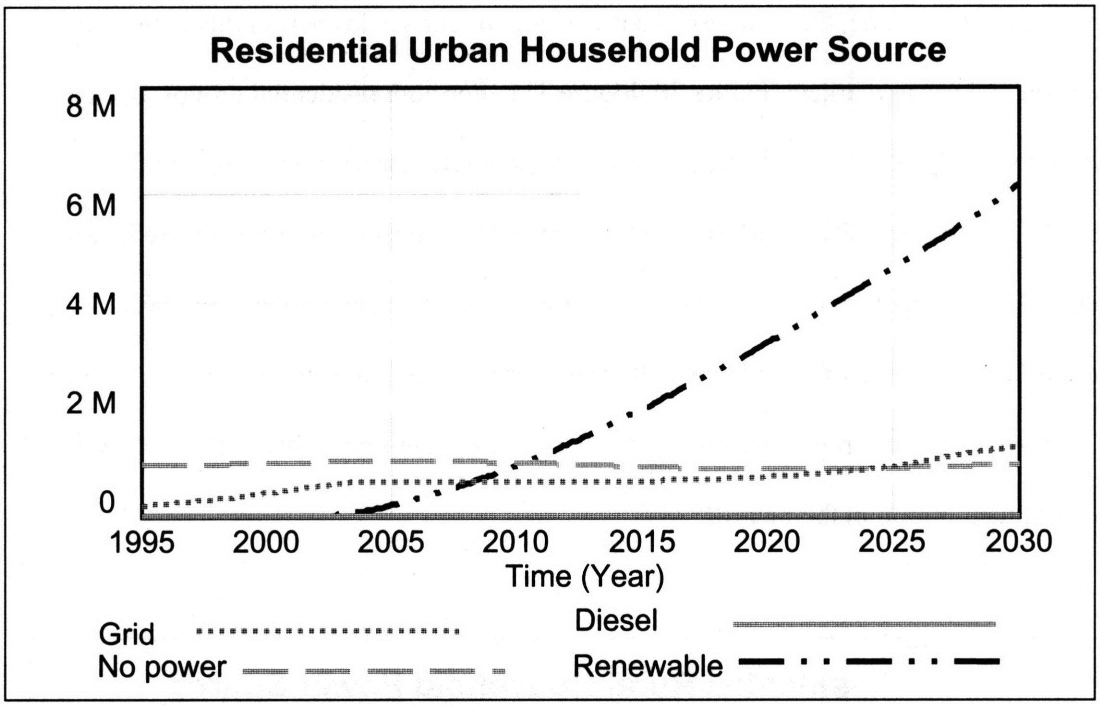


Figure 31: Urban residential households by power source - Base case

Given the parameters of the base case, the demand for grid-based generation capacity continues to grow, but at a very slow pace (Figure 32).

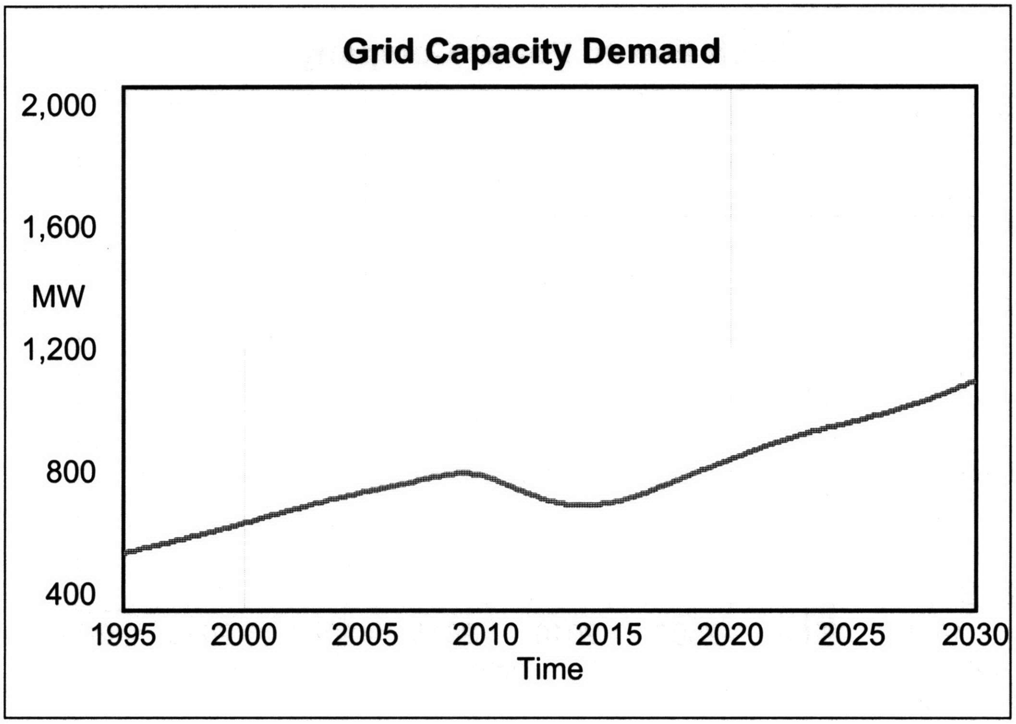


Figure 32: Overall generation capacity demand - Base case

Early in the run, the grid is the dominant choice but there is no investment in capacity. With this revenue and the government bailout (see Chapter 3), the power company is able to improve its cash flow (Figure 33).

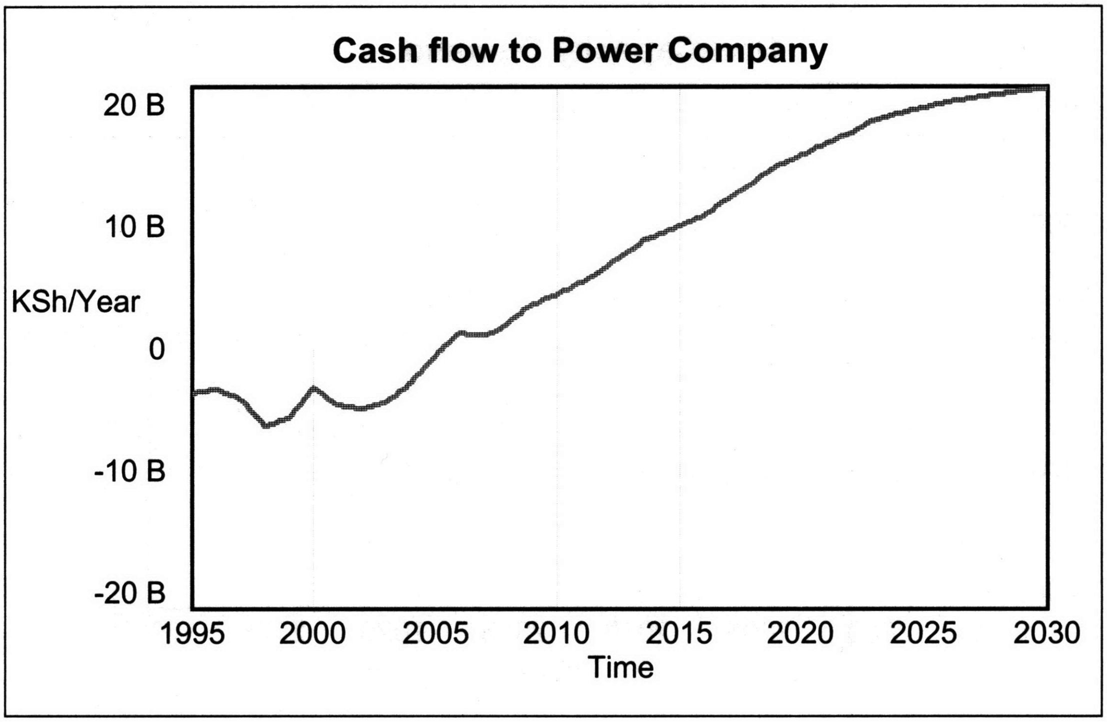


Figure 33: Power company cash flow – Base case

As a result, the power company is able to invest in added capacity and improve the reliability of the system (Figure 34,Figure 35).

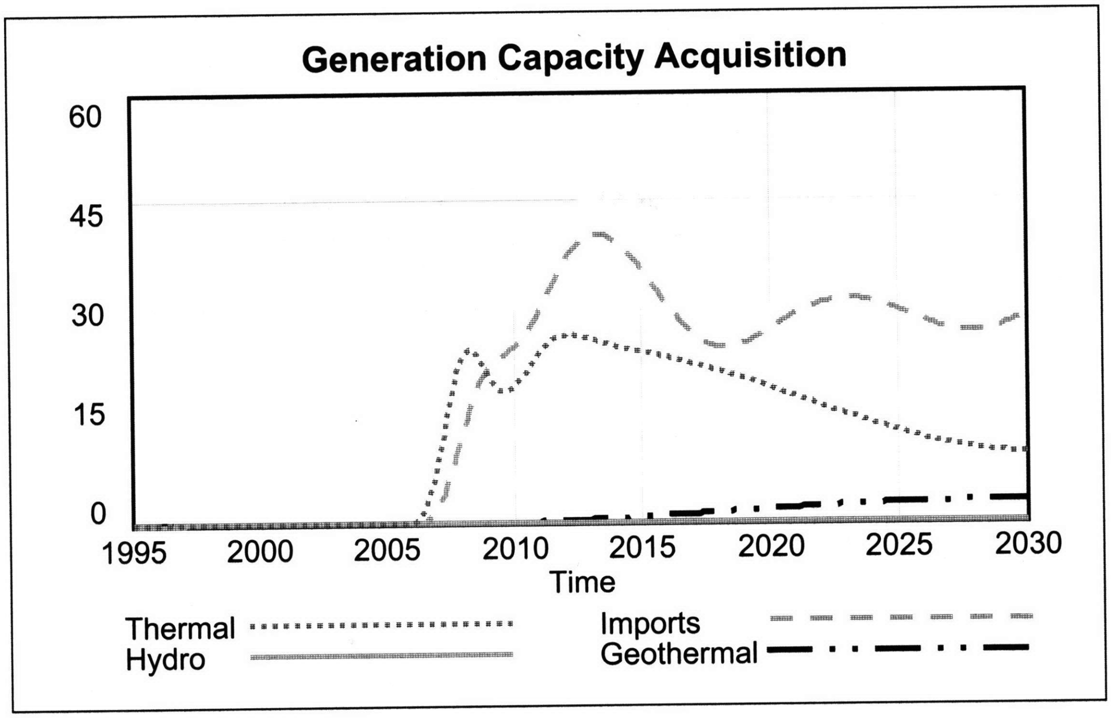


Figure 34: Capacity additions - Base case

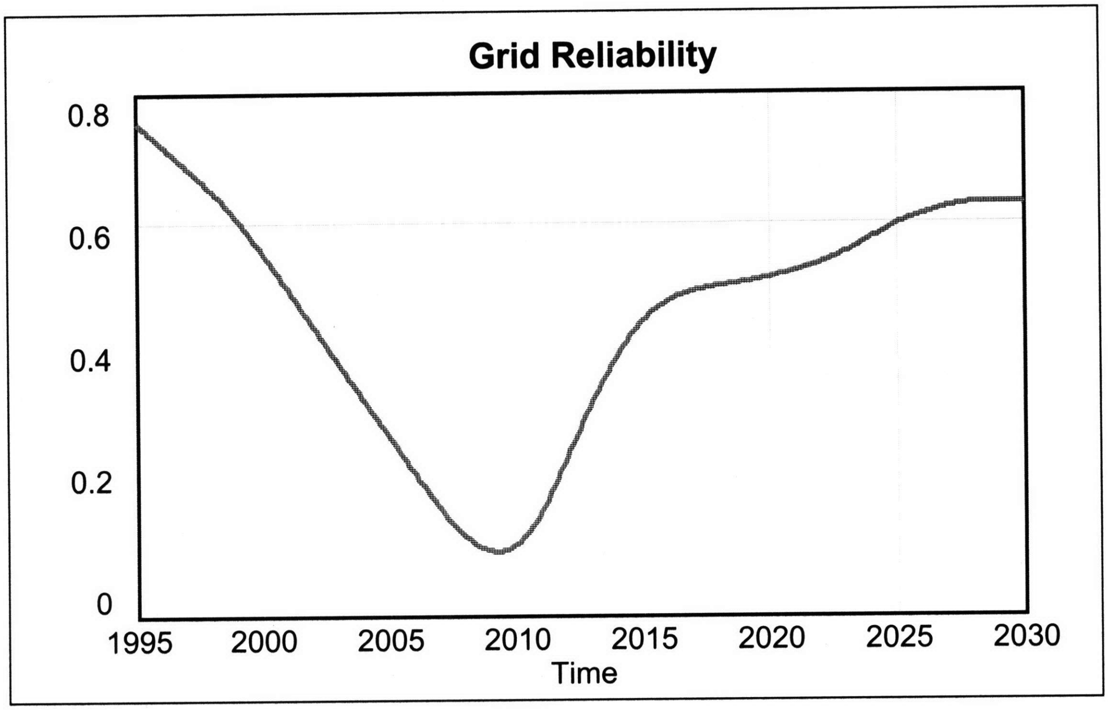


Figure 35: Reliability of system - Base case

The improvements in reliability result in a larger industrial indicated market share for grid in the second half of the run (Figure 36).

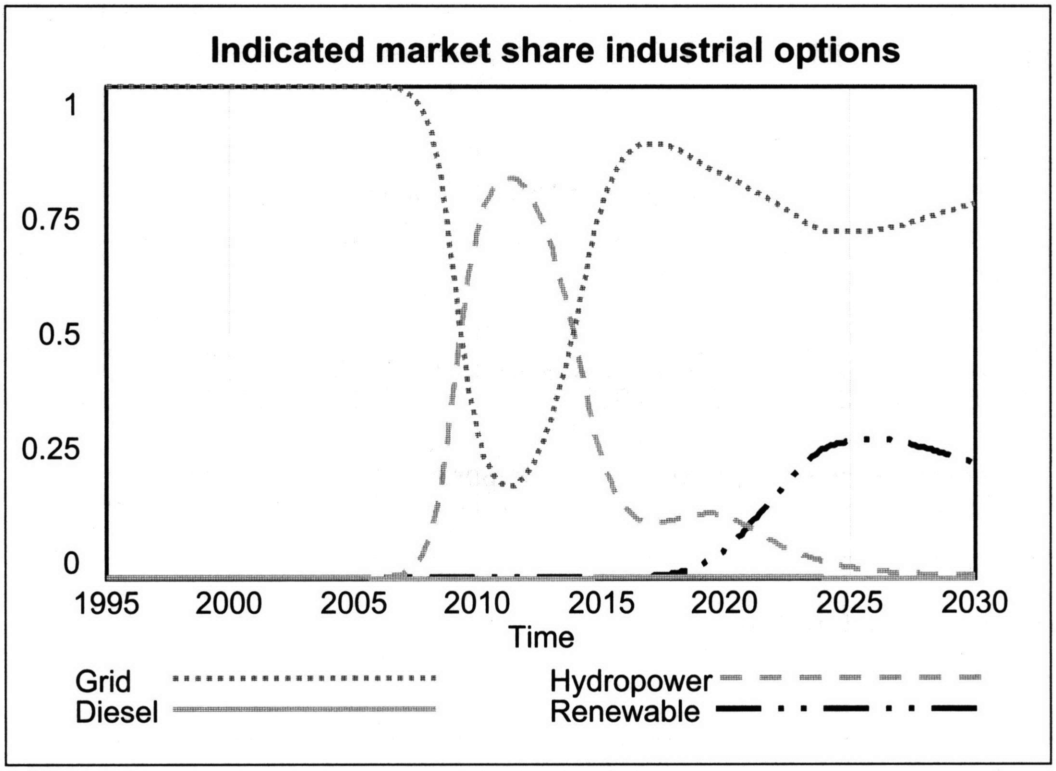


Figure 36: Market share of industrial options - Base case

Figure 37 shows the actual market shares as the consumer decisions impact the system development. Note that the grid maintains 75% of the market, even though at times the off-grid options are more attractive.

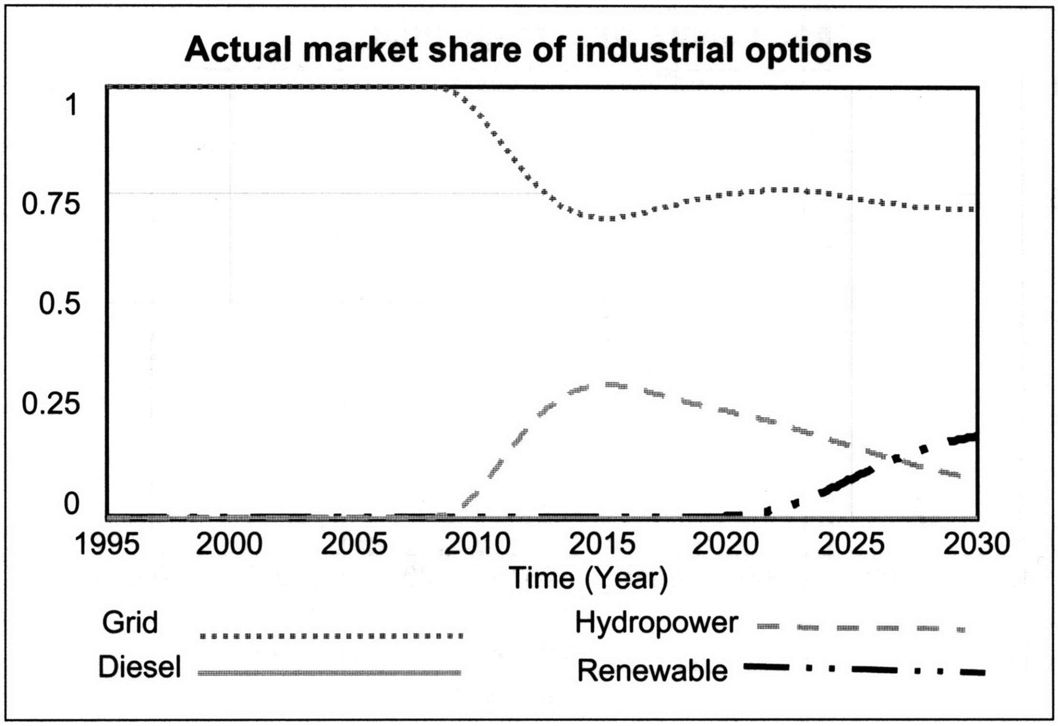


Figure 37: Actual market share of industrial options - Base case

As stated above, in residential markets the price of PV passes below grid at the time when reliability of grid is improving. This prevents the grid from being the dominant choice late in the run as was seen in the industrial case. Instead, PV keeps the largest indicated market share in both rural and urban markets (Figure 38, Figure 39).

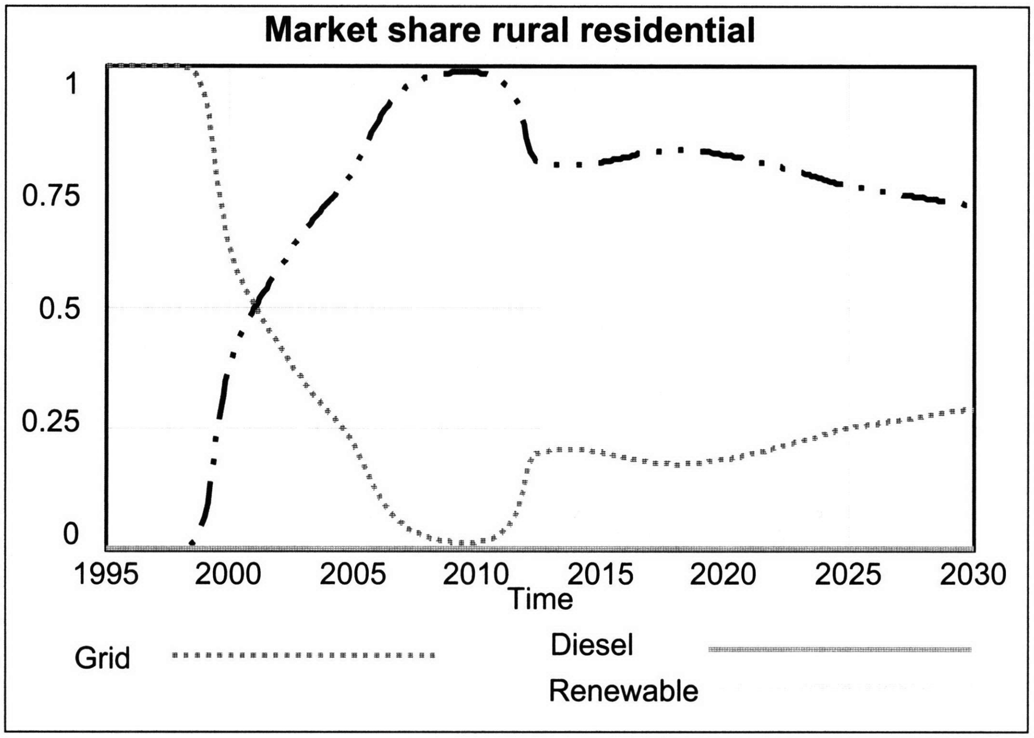


Figure 38: Market share of residential options, rural - Base case

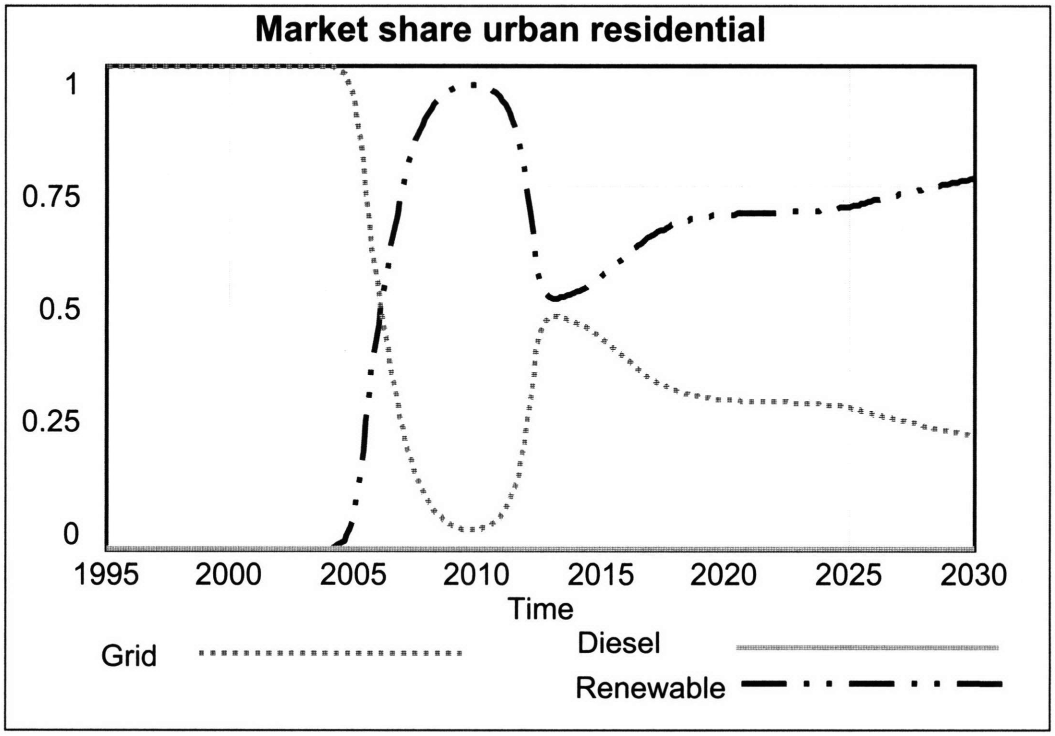


Figure 39: Market share of residential options, urban - Base case

Figure 40 shows the actual market share of the residential options, including both rural and urban customers. This result shows the potential for photovoltaics to become the dominant electricity source in the market.

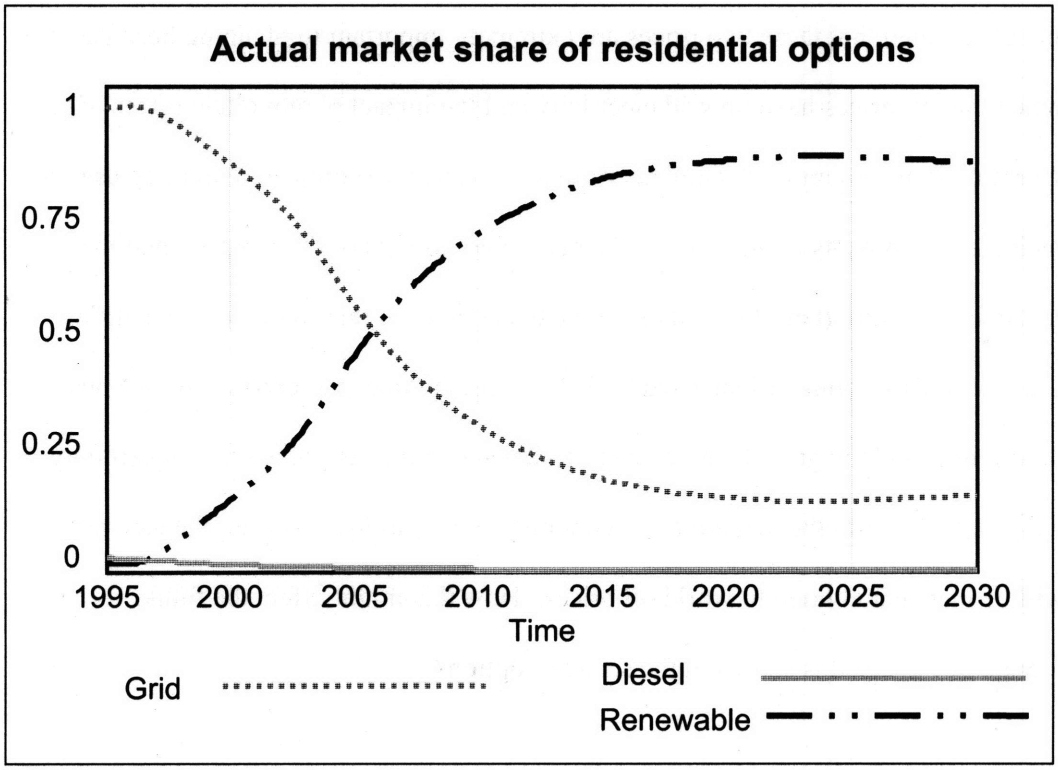


Figure 40: Actual market share of residential options - Base case

The preceding figures from the model exhibit the basic dynamics. Grid sales to industrial and residential consumers generate revenue for the power company, which will invest in capacity when it has sufficient resources. The capacity relative to demand determines reliability and influences the indicated market shares and subsequent sales.

Policy implications from base case

There were several key policy findings from the base case run of the model. The first two relate to Kenya's planning based on the exogenous prices of oil and photovoltaics. The model revealed that these two prices are extremely important to planning because of the impact that oil prices have on grid electricity and the impact photovoltaic prices have on off-grid options. Planning documents from Kenya show the projected oil price used in forecasting developments in the power system are very low (about $25/barrel) and the model shows how important it is to include the uncertainty in this figure in calculations. The Least Cost Development Plan used by KPLC for planning grid expansion assumes uncertainty in economic growth and electricity demand, but does not assume uncertainty in pricing (2005). With the depletion of economic sources of hydropower, the Kenyan grid will be increasingly tied to world oil prices. How this might affect the future development of the grid is shown in the scenario options.

The price of photovoltaics is a similarly important policy lever. The sensitivity to PV price shows the impact on indicated market share that could come from a reduction in the "surcharge" on PV pricing in Kenya. This could be approached from two sides. Either government planners could work to reduce to added cost to PV, in order to make lower cost PV more accessible, or they could work to keep prices high in order to protect the grid as the primary power option for consumers. The model and this research does not have a bias towards one policy over the other, but points out the potential options for policy interventions in this case.

Apart from the price issues, there were also policy implications from the base case related to the supply of electricity and the overall system architecture. The model makes it clear that there is a gap in the supply of electricity compared to demand. This is less obvious in the industrial side of the model, but very clear in the residential component. There is a very large population who is not connected to the grid and would like to be. Why is the unmet demand not being met? The simple answer of low customer ability to pay doesn't hold since the model does not include residents below the poverty line and the fieldwork showed many people had paid for electricity connections are were waiting long periods of time for connections. Another simple answer would be that KPLC lacks the manpower or capital to make the connections, however this reasoning does not make sense either. First, because KPLC has a relatively high employee to customer ratio, and second, because even if KPLC were not capable of making the connections, there is a clear market for private power producers to fill the gap. There is definitely significant risk in starting a power supply business in Kenya, but it would seem that the potential market and earnings are high. In this case, is there a policy measure which could incentivize either KPLC or private companies to meet the customer demand for power connections?

An additional concern with meeting the demand is the relationship between grid and off-grid suppliers. This tension was seen in previous work in South Africa (Steel 2003) and was noted by several informants during fieldwork (see Table 6). For now, the grid and off-grid suppliers act in competition with one another, however, in the future, grid customers are likely going to come from former PV connections. There is an interesting feedback where as you increase desire to be connected to the grid from PV, you create more demand on grid and the backlog increases, which increases sales of PV. As the "first generation" of PV users graduate to grid connections, they will make it more likely that the next round of consumers will want PV first. PV is a very logical waypoint in the energy ladder, but it is not currently be used as such. With policies that encourage collaboration between grid and off-grid, users might more efficiently move from no connection, to low-grade power connection, to grid connection. One option for encouraging initial purchase of PV panels, with the intention of building demand, is to offer a buyback program where the panels can be turned back in for re-distribution in other areas. The high durability and long life of PV panels would make this a viable option.

Clearly the behavior in the model is based on the assumptions described in Chapter 3. One of these assumptions, the bailout or default on debt repayment by the power company, represents a policy choice. For the base case, it was assumed that there is a government bailout in order to help make the power company solvent. This was included to reflect the real situation, where the government will not allow the company to fully collapse. Removing the bailout would result in the power company never gaining the revenue needed to recover its footing as seen in Figure 41. Several factors contribute to the recovery of the power company. First, the cash flow from the bailout allows it to regain its financial footing. There is an additional contribution to the cash flow from the lack of building during this period. While these factors help the financial aspect of the system, the reliability becomes worse and worse. However, this downward spiral is mitigated by the shift to off-grid by many industrial users. As this load leaves the system at the same time that the power company is now able to invest again, the reliability begins to improve and customers return. This is a cycle that is likely to repeat over a long time period.

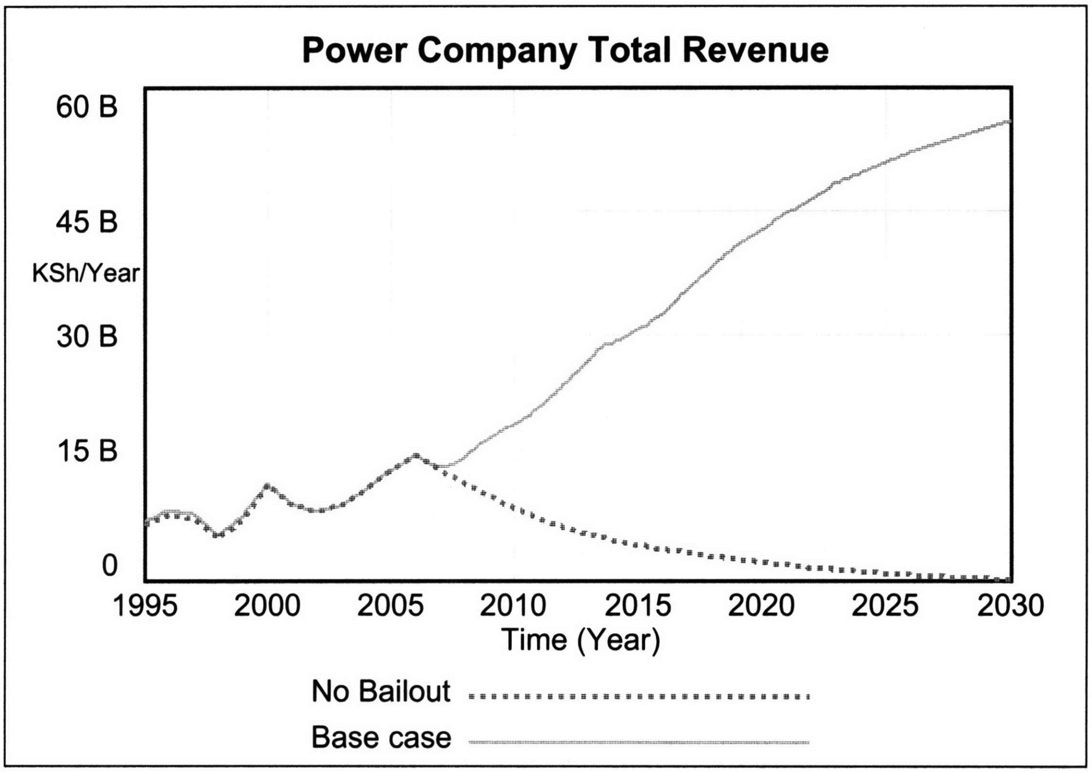


Figure 41: Power company revenue, with and without government bailout or default

It is interesting to note that electricity prices actually remain low if there is no bailout because there is no added generation capacity from more expensive sources. With the base system the majority of the electricity comes from hydropower. However, this keeps people on the grid and hastens the decline in reliability. Figure 42 shows the grid indicated price with and without the bailout.

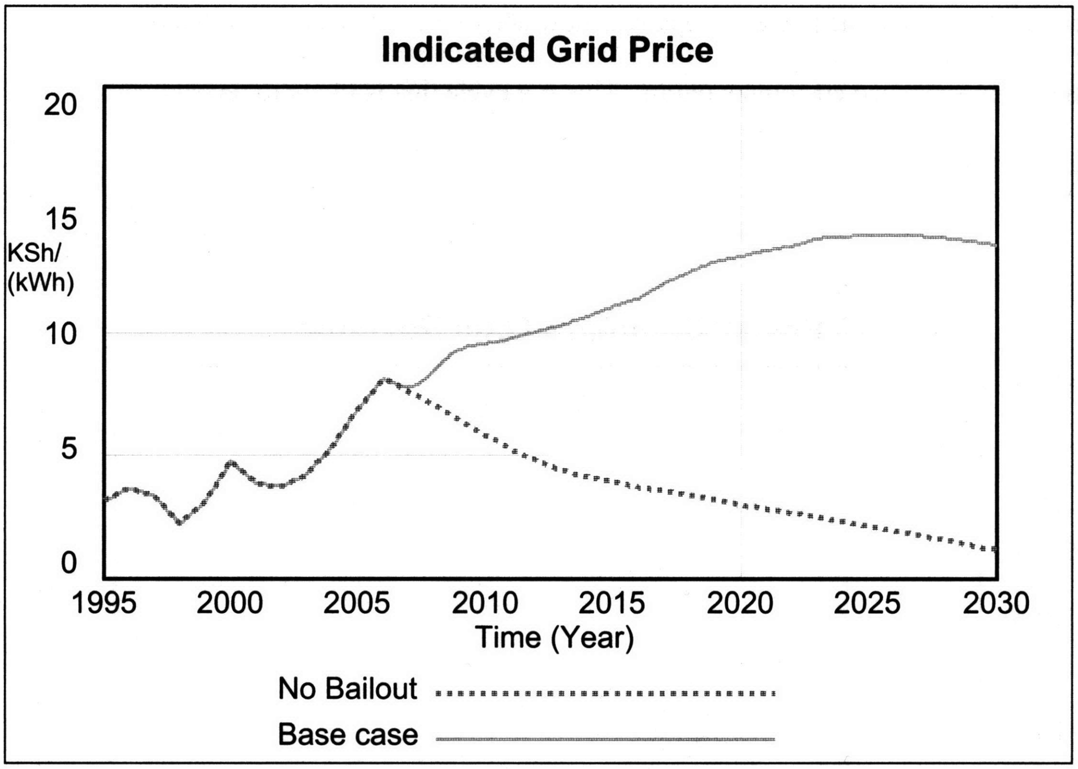


Figure 42: Grid price, with and without government bailout or default

The lesson from the bailout is that lack of investment and poor financial management can actually assist financial recovery, as long as the bailout can be expected. This feedback would encourage poor performance in the power sector. Therefore, policies need to be considered which could create incentives for strong performance.

Finally, the most broad policy implication of this research is the potential shift from centralized to decentralized system architecture. As noted previously, several authors have indicated the potential for and viability of industrial self-generation. Were this to happen in Kenya, or elsewhere in Africa, at a significant scale, it would drastically change the grid architecture. On one hand, this shift would potentially make the grid more robust and more reliable if the industrial generators are also selling back onto the grid. This could balance the load more effectively and inject power into the system at industrial sites that with the traditional architecture are far from generation sites. However, these gains are only possible if the industrial self-generators remain grid connected. If industries instead "island" themselves with either self-generation or a dedicated supplier, there is no benefit to the grid, apart from the initial reduction in stress on the carrying capacity of the system. In a largely decentralized and disconnected system industries will not have to worry about grid reliability, but they may be unable to take advantage of less expensive sources of bulk power if they come online in the future. From the grid side, if they become a primarily urban provider they may not see gains from economies of scale and may not be able to increase their load factor since the connected population will be relatively homogenous. This research does not offer a prediction of which system is superior, but it identifies that this is a potentially great change in the way power systems are structured in areas where there is currently limited grid infrastructure.

Scenario exploration

Exploring scenarios shows how the system might respond to changes in the operations and market in the future. The scenarios explored using this model included adding endogenous elements and varying exogenous inputs. As described at the end of Chapter 3, one of the findings from the modeling process was the feedback gaps in the power system operations in Kenya. The first scenario explores what would happen if the power company was able to meet the full demand for power connections, as well as collect all payments for service. The second and third scenarios experiment with the price of generation in the future. The base model found the system was very sensitive to the price of installed PV. The second scenario explores a shifting PV price, both exogenous and endogenous inputs. The base case model also found the system was highly sensitive to the world price of oil, yet the projected price of oil used in all Kenya planning documents is very low. The third scenario tests what happens with the system for low, medium, and high projections, as well as a fluctuating, price for oil.

Power Company Responds: *Supply meets demand*

The first scenario explores what would happen if the power company improves its quality of operations. This improvement includes basic operations like meter reading and bill collection, as well as meeting the demand for power connections. Table 12 summarizes the changes to the model under this scenario.

Variable	Base Equation	Scenario 1
PowerCo Percent meters read	= 0.85	Ramp 0.85-1 from 2005-2010
PowerCo Percent bills collected	= 0.85	Ramp 0.85-1 from 2005-2010
PowerCo Corruption tax	=0.05	Ramp 0.05-0 from 2005-2010
PowerCo Connect capacity	PowerCo Connect target[Population]*PowerCo Connect success percent	Desired Grid Connect from NoElec[Population]+ Desired Connect from Diesel[Population]+ Desired Connect from Renew[Population]

Table 12: Model changes under scenario *Supply meets demand*

The first two changes are variable changes that assume power company performance will increase over time until it is 100% in terms of meter reading and bill collection. The ramp function is used to estimate a gradual, rather than sudden, change in performance. Similarly, the change in corruption tax from 5% of the budget to 0 over a five year period assumes that KPLC improves performance and is no longer losing a portion of its budget to corruption. The change in KPLC connection capacity makes the capacity endogenous. Instead of trying to meet an exogenous target, the variable PowerCo Connect capacity is set equal to the indicated desired grid connection from non-connected and off-grid households. This change ignores some of the realities of KPLC's capacity since it has to be assumed that the company would be connecting as many people as possible. This approximation assumes that the company is able to address the supply bottlenecks in the future and is able to serve every willing customer.

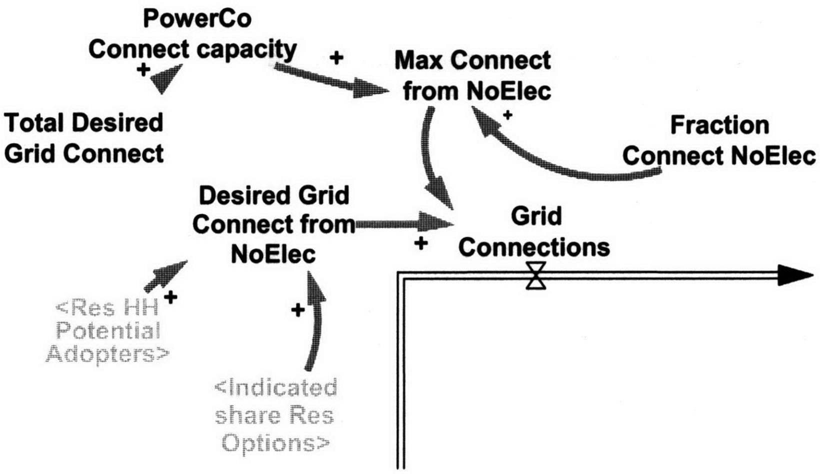


Figure 43: Added structure for scenario *Supply meets demand*

Most of the results from this scenario are obvious. If the connection capacity of KPLC is improved, more households will be able to be connected to the grid and fewer will turn to PV as their electric power source (Figure 44, Figure 45).

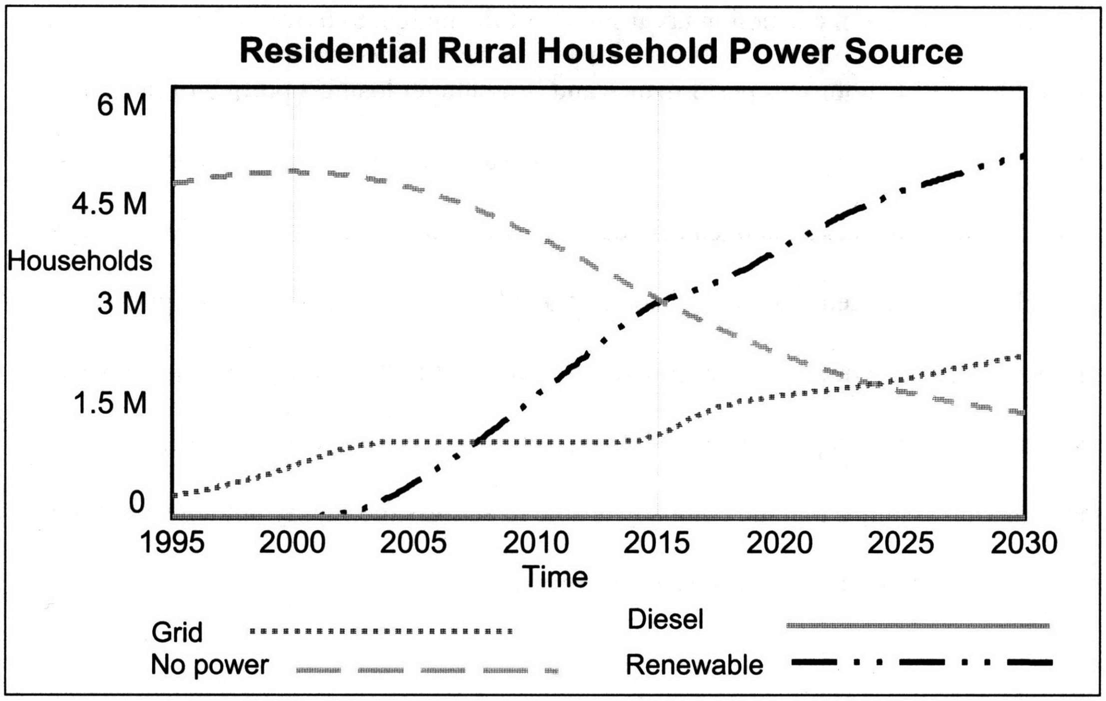


Figure 44: Rural residential households by power source - Supply meets demand

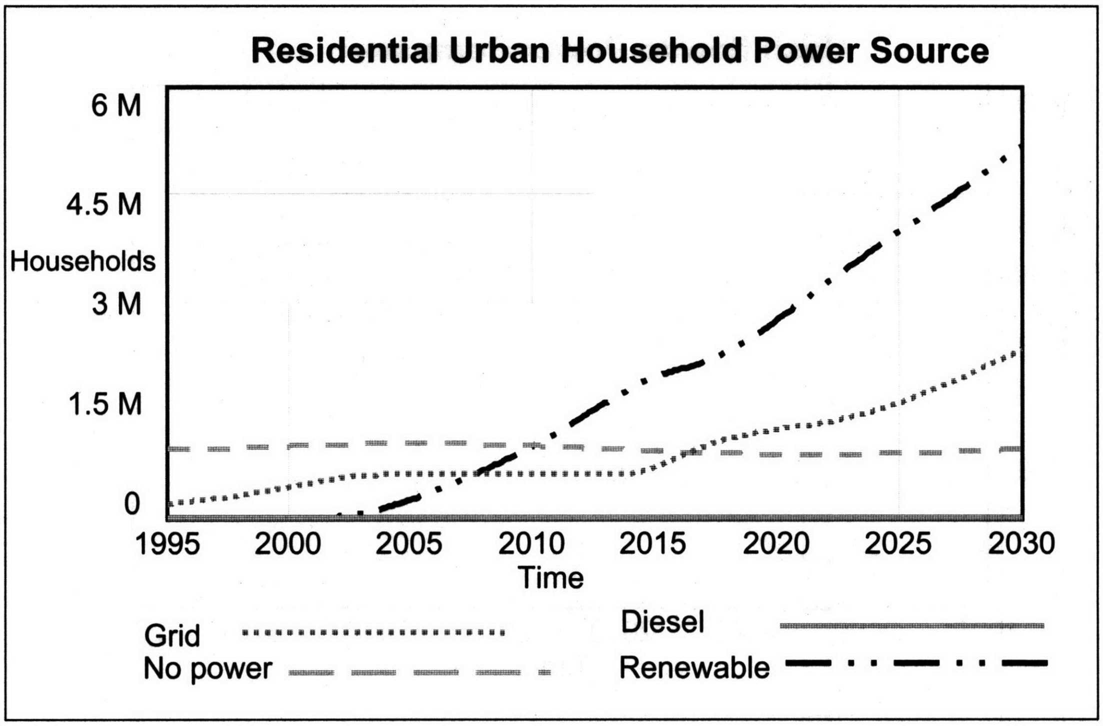


Figure 45: Urban residential households by power source - Supply meets demand

It is worth noting, however, that renewables will still be the primary power supply in the future, even with improved performance by KPLC. Although improvements were made to increase the revenue stream, there is still a lack of capital at the beginning of the model that leads to under capacity and unreliability (Figure 46, Figure 47). KPLC will need to find even more ways to increase revenue and investments to keep PV from being a preferred choice to grid.

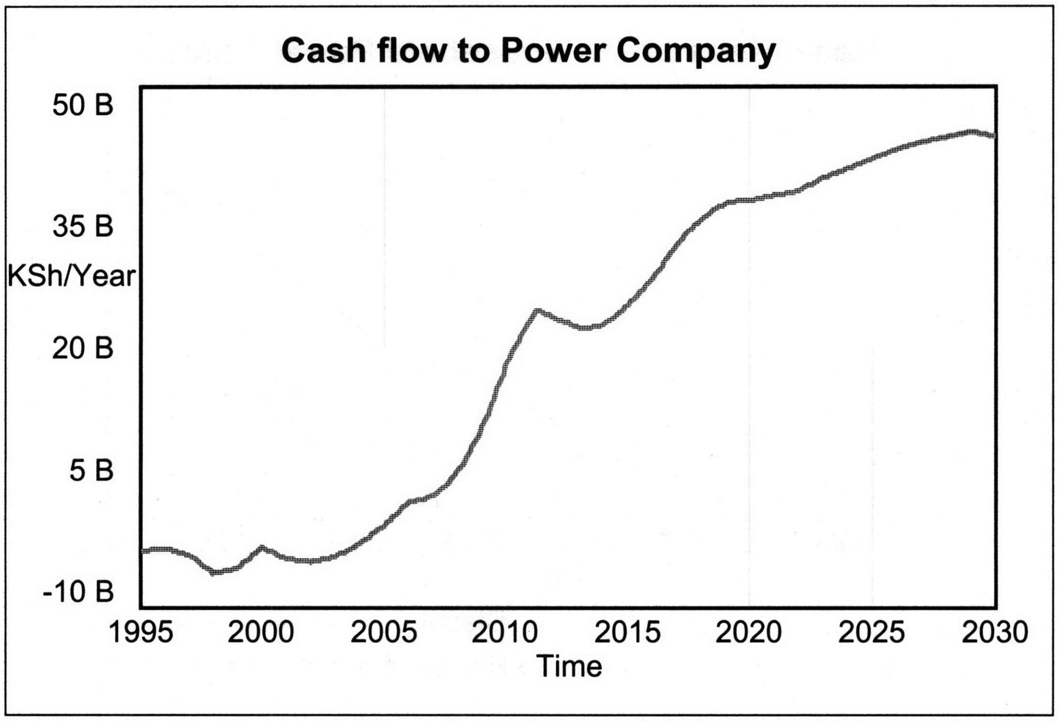


Figure 46: Power company cash flow - Supply meets demand

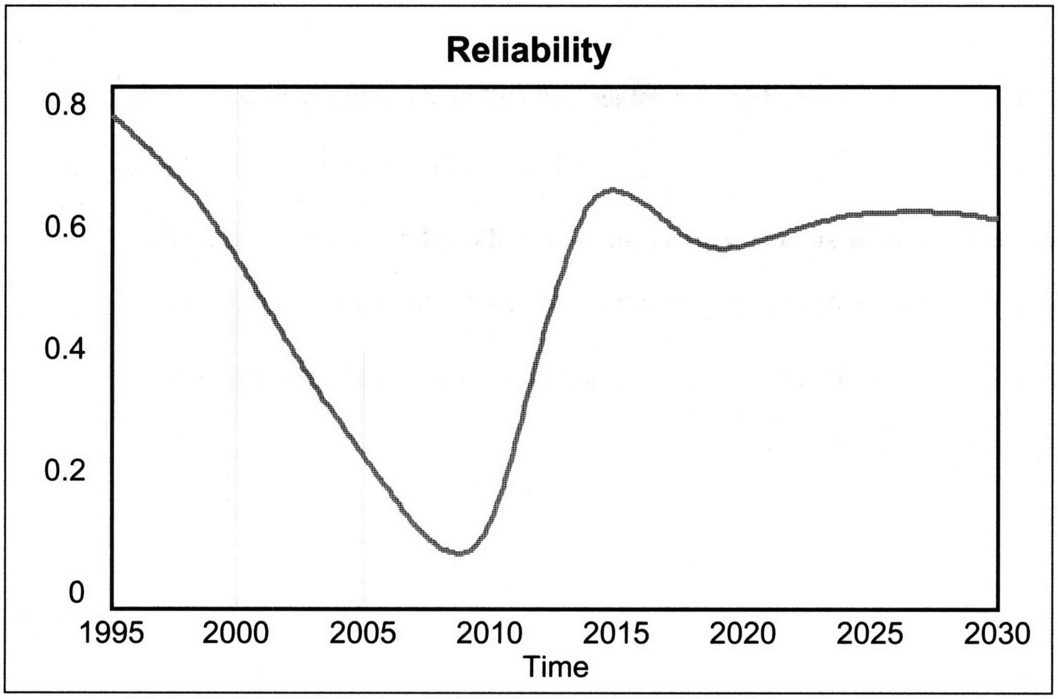


Figure 47: Reliability - Supply meets demand

Figure 48 shows the indicated market share for rural residential consumers under this scenario (urban residential follows essentially the same pattern). It shows the impact of low reliability on the consumer preferences. As with the base case, the grid is able to regain market share against renewables, but then loses preference again as the price of PV continues to fall. Compared to the base case, the grid is able to make more of a rebound due to the improvements in KPLC.

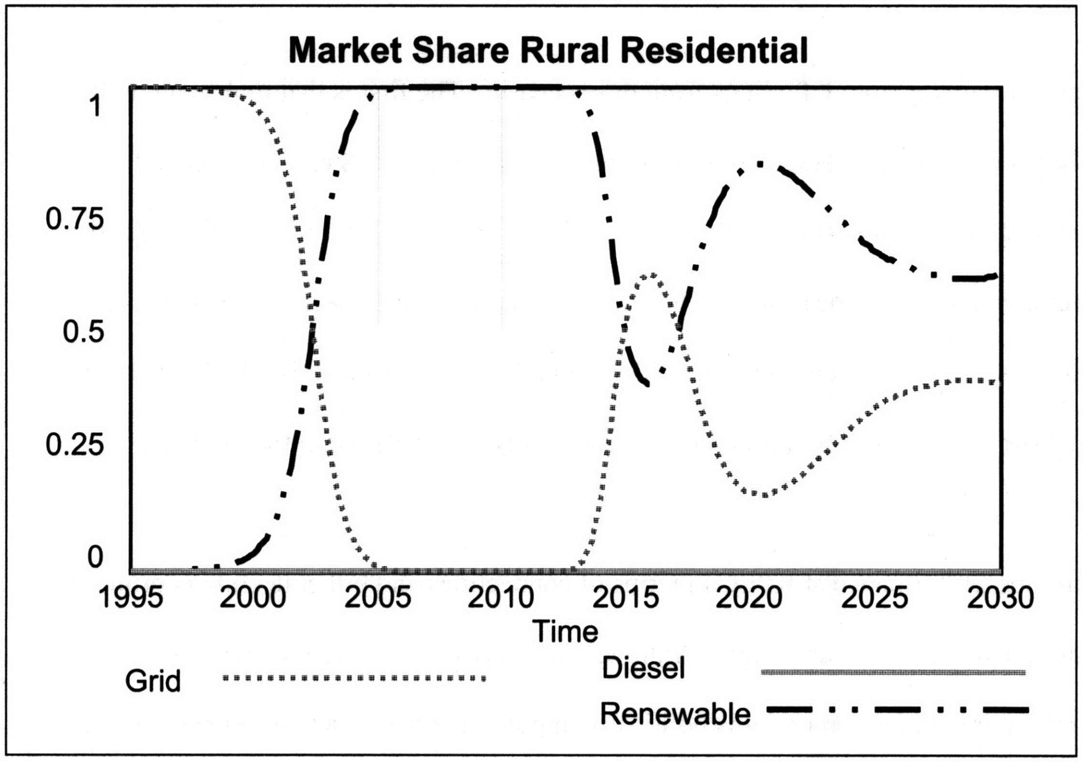


Figure 48: Indicated market share, residential - Supply meets demand

Without the backlog created by the low connection capacity of KPLC, grid is more able to compete with renewable off-grid systems. However, reliability pushes the majority of consumers to off-grid, regardless. Although halfway through the model run the grid appears to be gaining ground, it loses market share to PV due to continuing price drops in the cost of photovoltaics. In the end the final results of the model are roughly the same as the base case. In addition, it is unclear if this level of capacity is even within reach for KPLC. At the end of the model run, KPLC would need to be making 250,000 household connections per year. As a final note, under this scenario a greater percentage of power company revenue will come from residential customers, which would possibly create feedback to the supplier to make greater efforts to meet residential demand.

There are two key policy findings from this scenario. The first is that improving KPLC service is not a high leverage point for improving the overall system. The second is that the strategy of low investment, given an assured bailout, may be a viable option for the power company in the near term. The latter was not a finding specific to this scenario, but an observation that emerged from beginning the scenario analysis. At the end of the model run, the grid is still unreliable and not the dominant choice in the market.

Improving performance at KPLC in terms of connections and bill collecting is primarily focused on residential consumers. Although this may not be a high leverage point for overall system improvement, it is politically important. One of the interviewees from KPLC noted that industry drove the economy, but that residents voted. KPLC is obligated to meet the demands of both groups. Although politically the demand is for expanded access, improved quality in industry may have a greater direct impact on poverty. In the examples of losses due to poor power supply described in the quotes in Chapter 2, the added cost of production is passed to the consumer and raises the cost of food and goods. Basic or “lifeline” electricity connections, which are typical of rural electrification, provide only enough power for lights, radios, and some televisions. Rarely can these connections be used for income generation. For an individual household, it is unclear whether there would be a greater impact on the family budget from a low-supply electricity connection or a reduction in the cost of food and other products.

If performance at KPLC continues to be poor, they are still likely to be able to regain footing through government bailouts and international support. This brings up question of whether or not the power company should be allowed to fail and if the government should continue to support it without performance improvements. This issue is not unique to Kenya or developing countries. In the US, the government has assisted industries when it was considered to be in the best interest of the overall economy or population. With the bailout, however, there is always a question of moral hazard and creating a cycle of dependency.

As a final point, there is also the question of whether meeting supply is even within the reach of KPLC If they are unable to meet current targets, how are they going to scale up to meet a much larger demand? This gap appears to be an opportunity for private electricity providers, but there needs to be proper risk guarantees and stable legal and regulatory structures to attract new entrants.

PV Price Shifts: *Taxes and subsidies*

The base case of the model also showed the dynamics were highly sensitive to changes in the price of photovoltaics in Kenya. The value for PV in the model is the world price of PV, plus a surcharge used to replicate the higher prices found in Kenya. The base case assumes that there is no additional change to the price apart from the decline in world prices due to the learning curve. Two options were explored for this variable. The first is a sudden change in the surcharge based on a subsidy or tax on the price of PV. The second is a feedback loop where the surcharge declines as the market in Kenya grows. The first explores policy options where prices are shifted exogenously through direct price-oriented policies, while the second explores the changes due to growth in the market whether through natural development or programs to encourage growth. Table 13 summarizes the changes to the model under the runs for the first version of this scenario.

Run	Base Equation	Scenario 2
Subsidy introduced, tested at 5 year intervals	Kenya PV Surcharge = $5/Watt	Kenya PV Surcharge = $0/W, Time = 2010, 2020
Tax introduced, tested at 5 year intervals	Kenya PV Surcharge = $5/Watt	Kenya PV Surcharge = $10/W, Time = 2010, 2020
Subsidy, then removed	Kenya PV Surcharge = $5/Watt	PULSE [0, 2010, (2,5,10)]
Tax, then removed	Kenya PV Surcharge = $5/Watt	PULSE [10, 2010, (2,5,10)]

Table 13: Model changes under scenario *Taxes and subsidies*

These runs tested not only the changes from the introduction of the tax or subsidy, but also the timing of the change. This was done to account for potential tipping points, after which the changes would be less significant. The initial runs assumed that once a change was made, it remained until the end of the run of the model. The second set of runs assumed that the subsidy or tax was introduced, then removed 2, 5, and 10 years later, again starting from a range of points in the run of the model. The second set of runs used the pulse function to initiate the change and vary the duration of the subsidy. This was tested both to understand the impact of policies designed to help the technology gain a foothold in the market and to understand the impact of shifting government initiatives. This type of shift was seen in South Africa's subsidy of basic electrical services.

Focusing on the industrial energy demand, Figure 49 shows the effect of introducing subsidies in 2010 and 2020 compared to the base case. In both cases, the subsidy (or simply lowering of the price of photovoltaics) results in a rapid decline in the energy demand for grid. As stated several times previously, this model is not intended to show predictions of what will happen in future scenarios, but instead shows leverage points for policy. Clearly changing the price of PV is one of these leverage points. In reality, there are constraints on PV in terms of installation space, battery cycling, temperature and efficiency, among many others. What this model shows is that you can have a dramatic effect on the market through reducing the cost of PV.

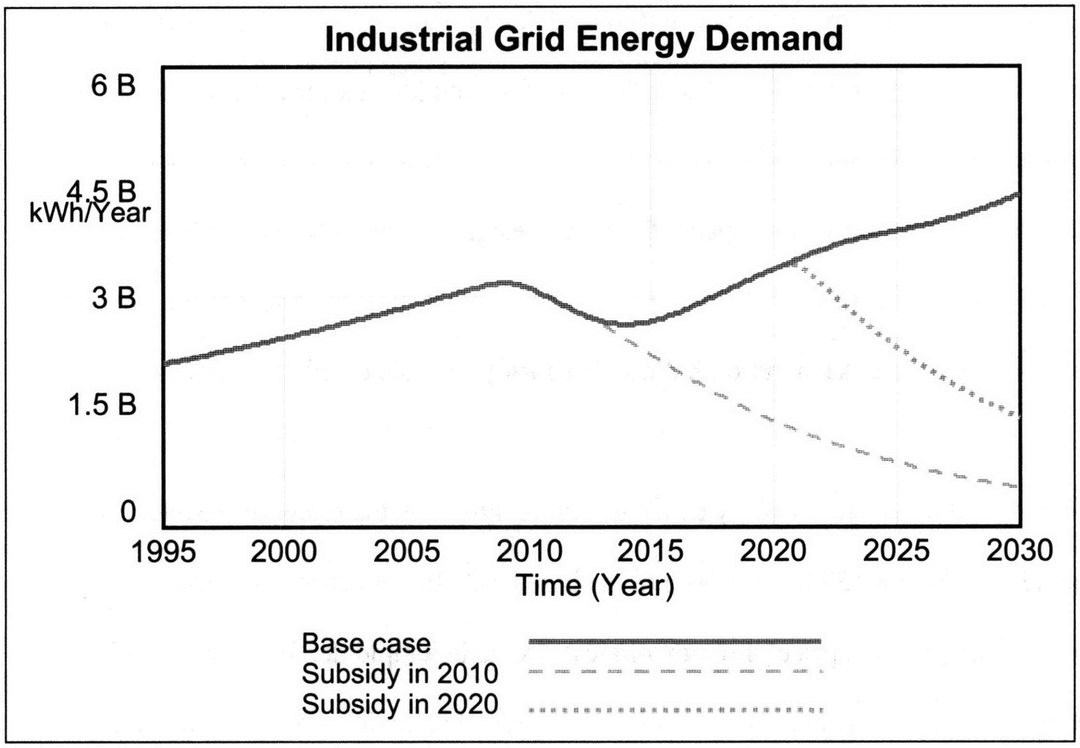


Figure 49: Industrial energy demand with PV subsidies introduced in 2010 and 2020

As would be expected, the decline in energy demand from the grid results in reduced cash flow (Figure 50). The reduction is not sharp in part because the lowered capacity needs mean less money is going into investing in new capital. As Figure 51 shows, the decline in demand for grid electricity actually improves the reliability on the system due to the decreased traffic and generation demand.

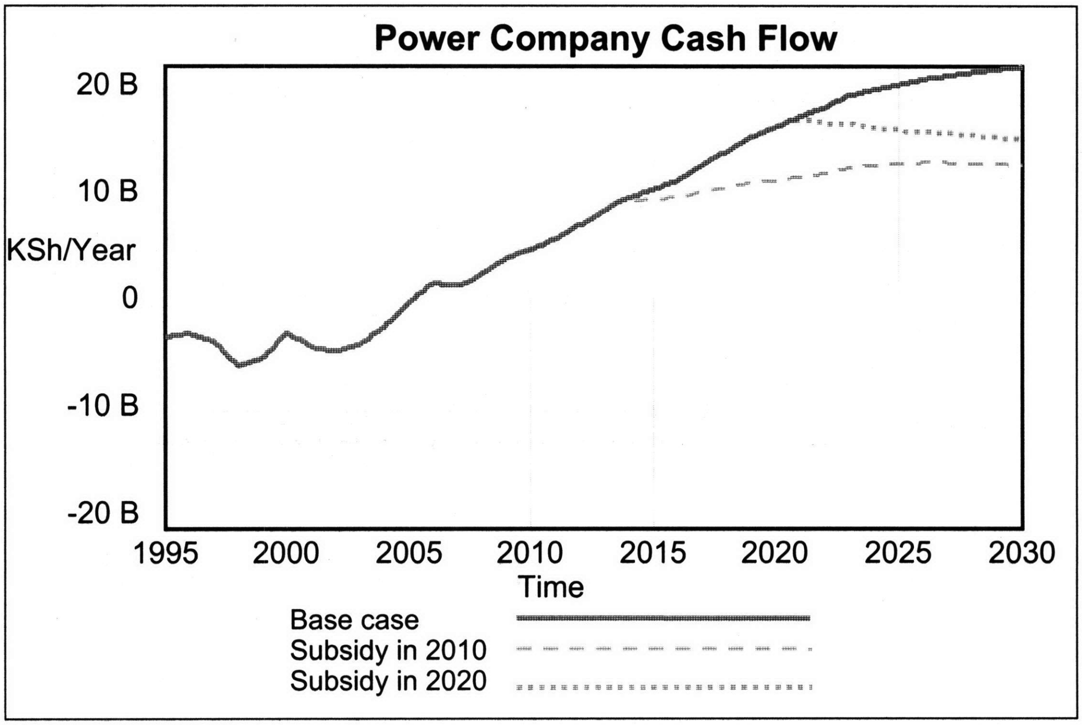


Figure 50: Power company cash flow with PV subsidy introduced in 2010 and 2020

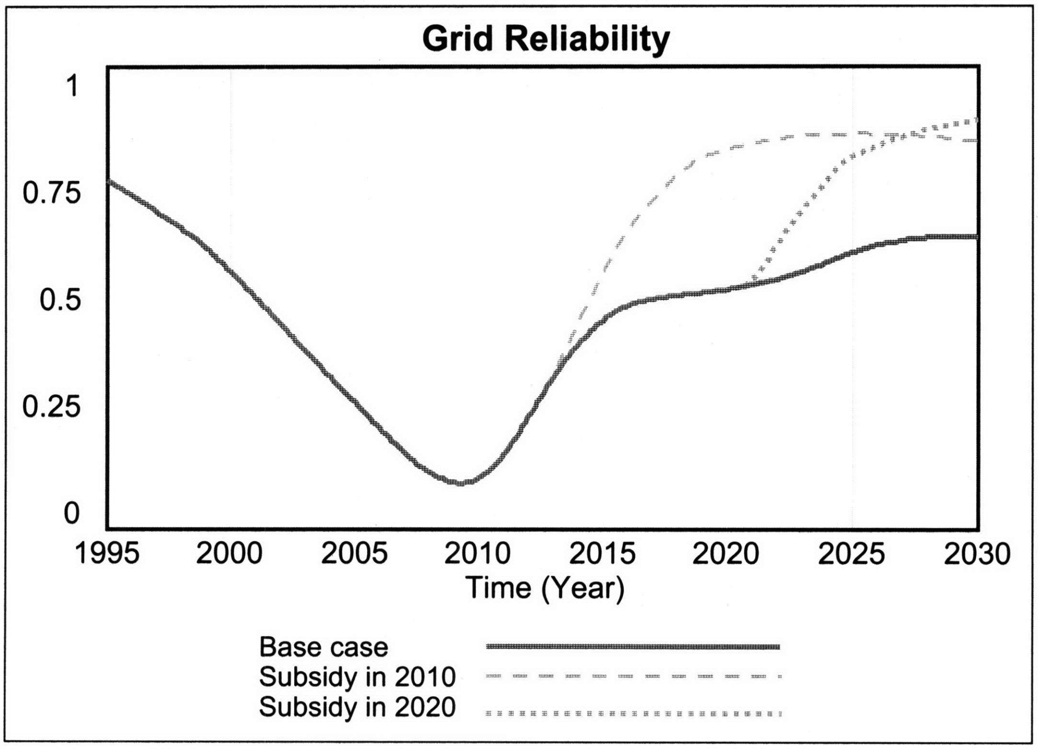


Figure 51: Grid reliability with PV subsidies introduced in 2010 and 2020

Overall, the PV subsidy has little impact on the residential market, since PV was already the dominant choice over the time period studied. Looking at the change in industrial indicated market shares, however, a subsidy introduced in 2010 will ensure that the grid never regains consumer preference the way it did in the base case run (Figure 52).

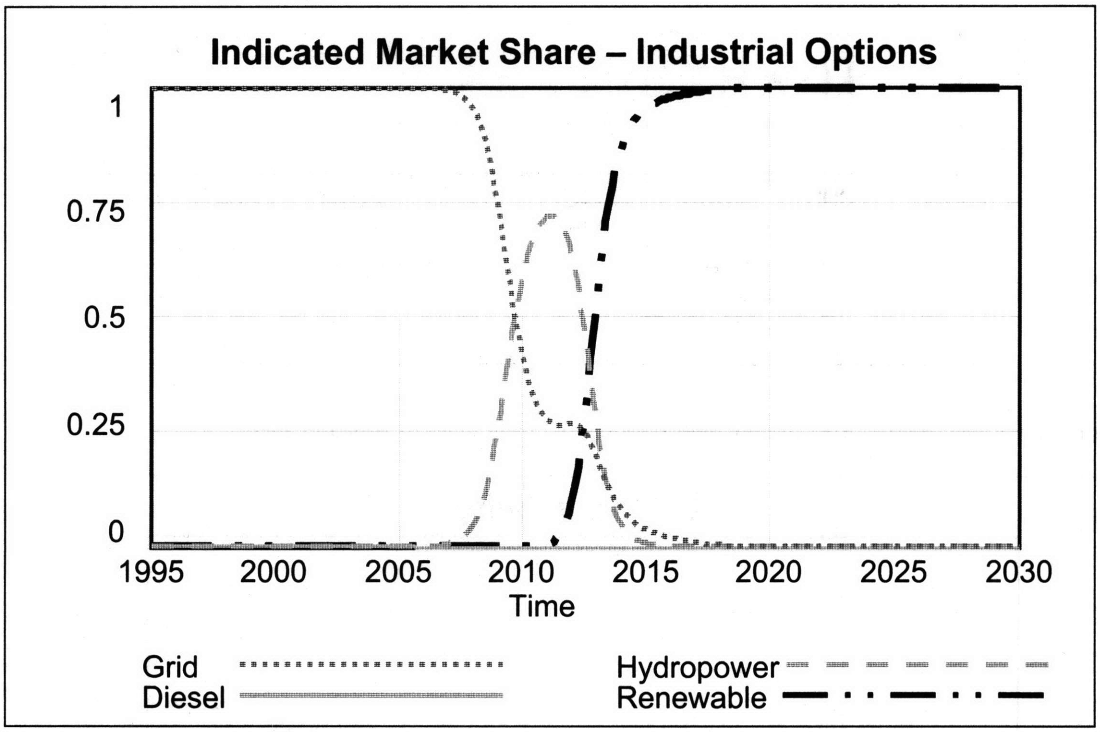


Figure 52: Industrial indicated market share – subsidy at 2010

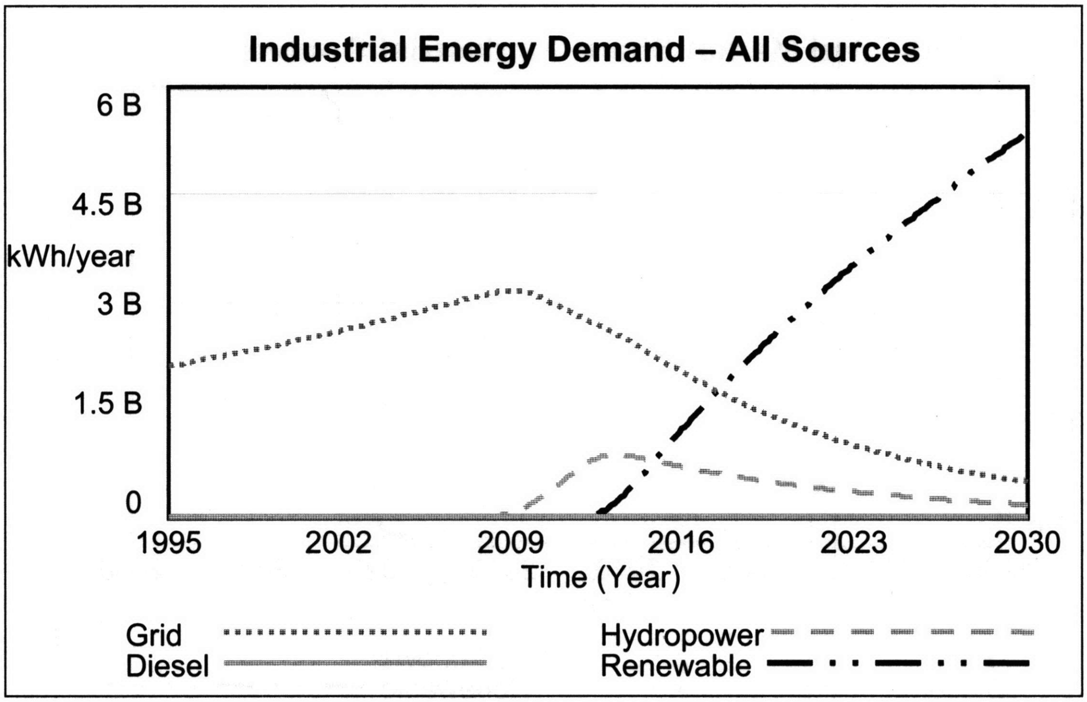


Figure 53: Industrial energy demand – subsidy at 2010

By comparison, initiating a subsidy at 2020 makes PV the dominant choice, but only after the subsidy is introduced (Figure 54, Figure 55).

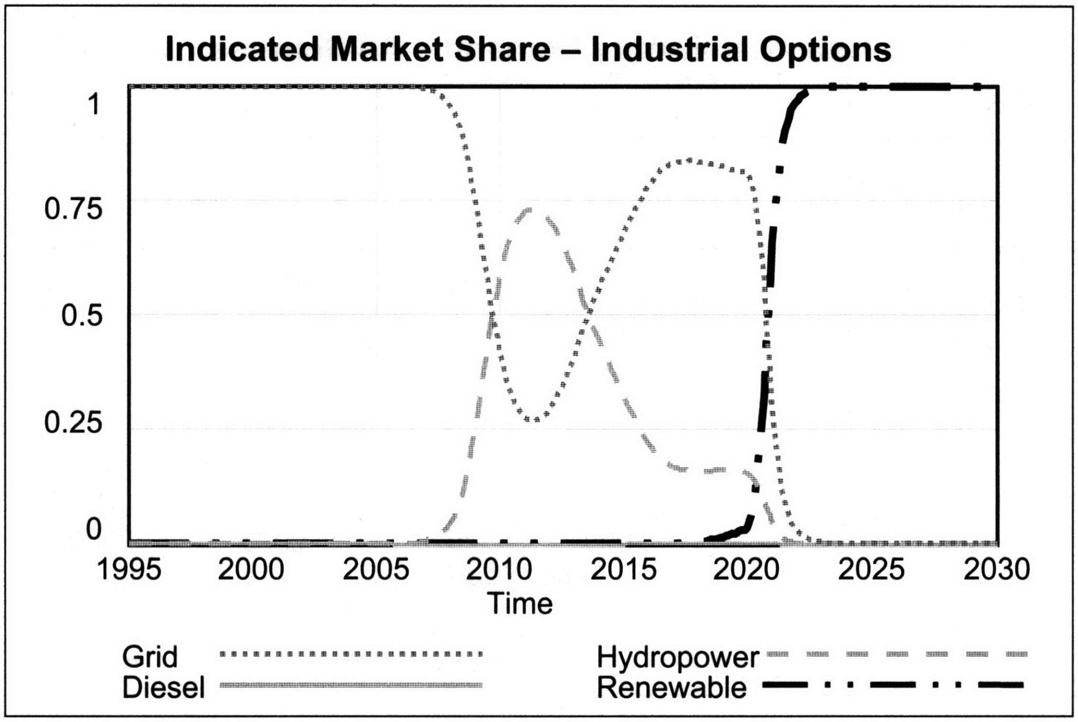


Figure 54: Industrial indicated market share – subsidy at 2020

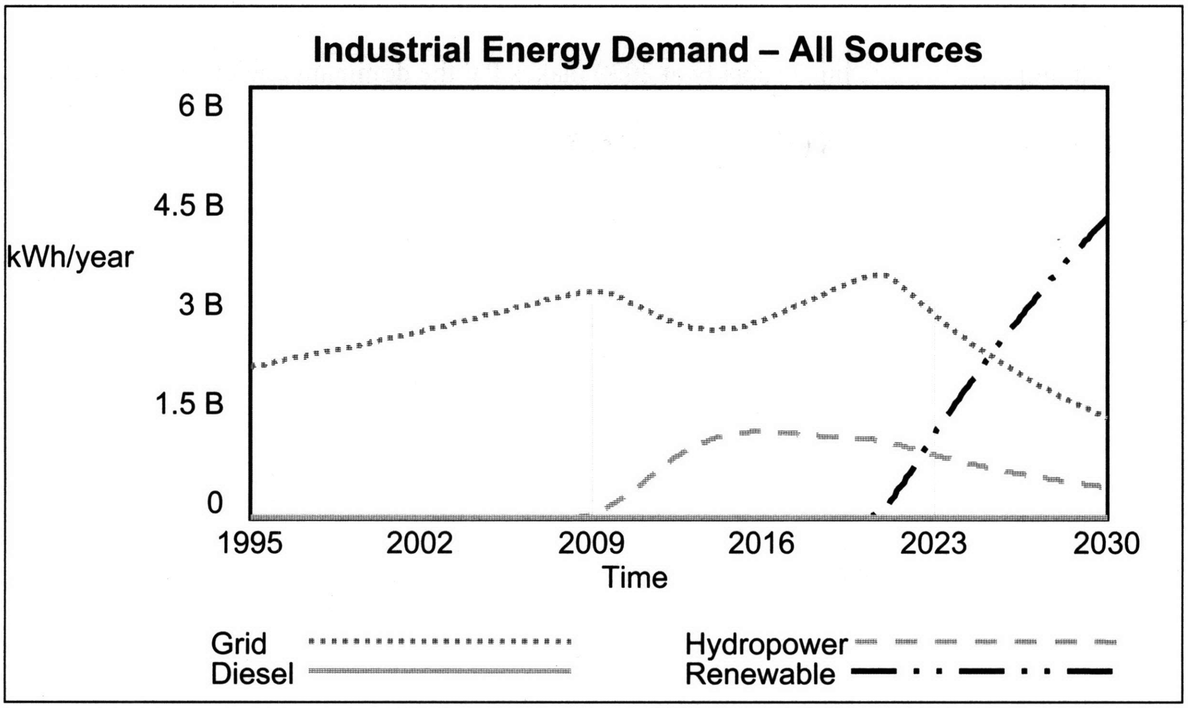


Figure 55: Industrial energy demand – subsidy at 2020

As a result, the actual grid share of the market declines to only 25% (Figure 56). The model has no constraints on technology diffusion so PV is able to scale-up very quickly when it becomes the dominant choice. Scale-up at this pace is likely unrealistic and the output from the model should be interpreted as the pressure on the market to implement PV as the electricity source.

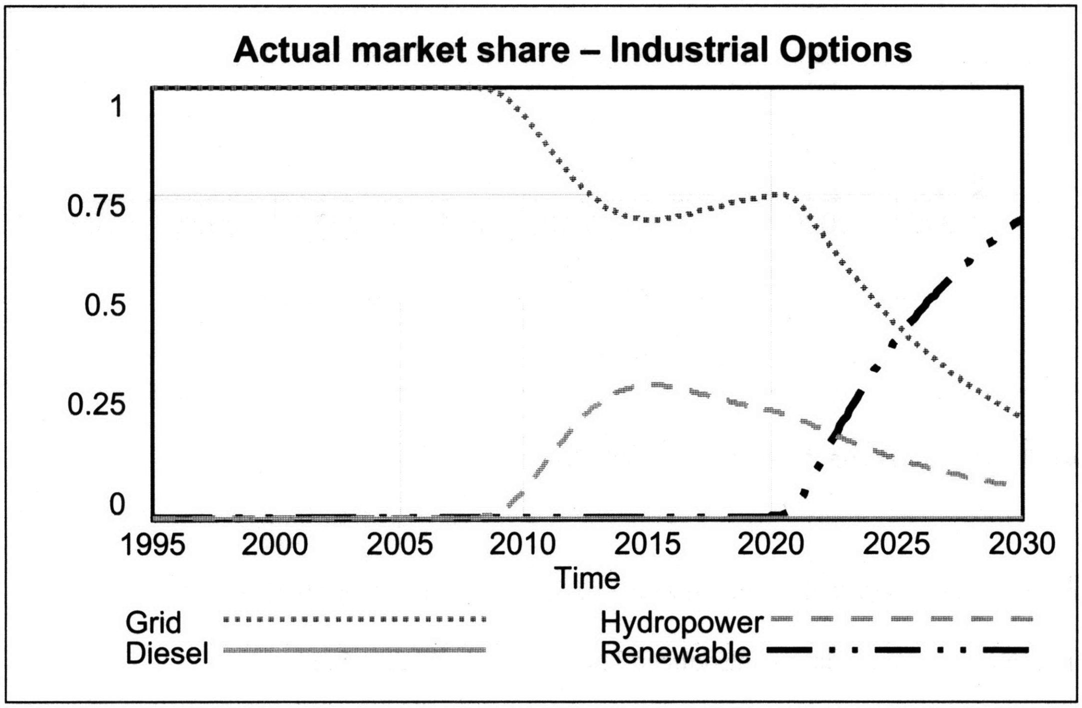


Figure 56: Industrial actual market share - subsidy at 2020

By comparison, introducing a tax where the cost per Watt is artificially increased under the same schedules used for the subsidy has little effect on outcomes. Introducing the tax later in the run reduces the grid demand because PV has already gained a foothold in the market, but introducing the tax in 2010 produces essentially no change from the base case (Figure 57).

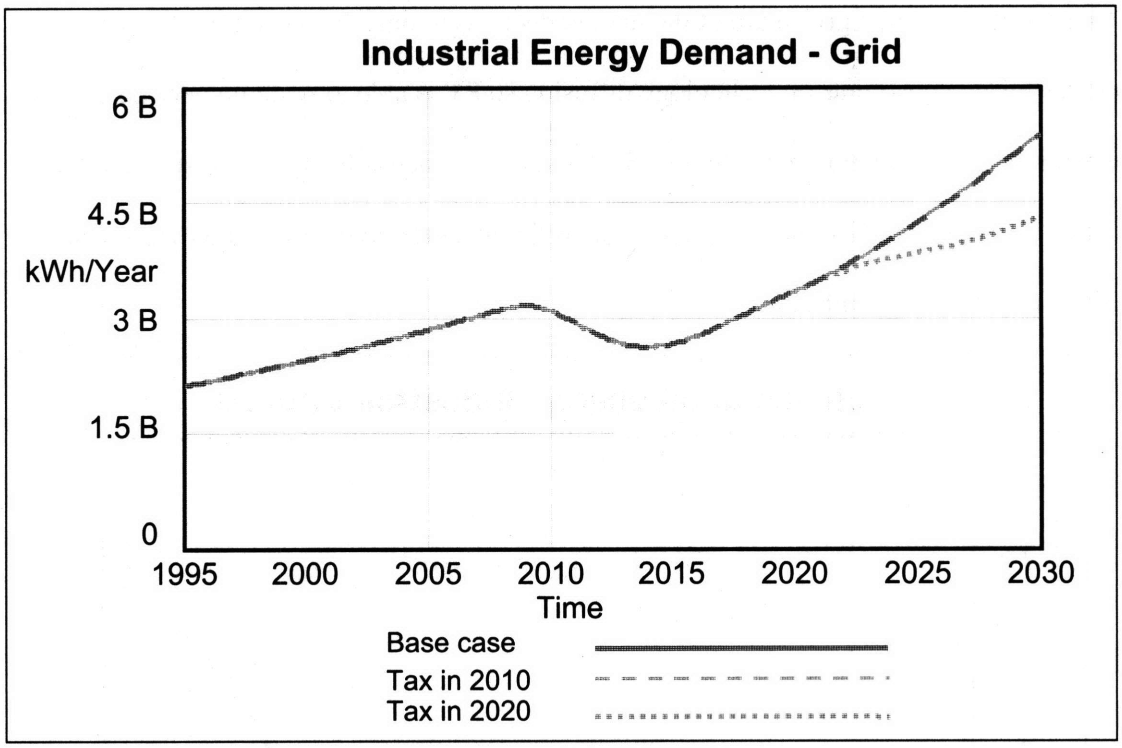


Figure 57: Industrial energy demand - tax at 2010, 2020

Similarly, the tax on PV has limited effect on grid reliability other than a slight improvement when the tax is introduced late in the run (Figure 58).

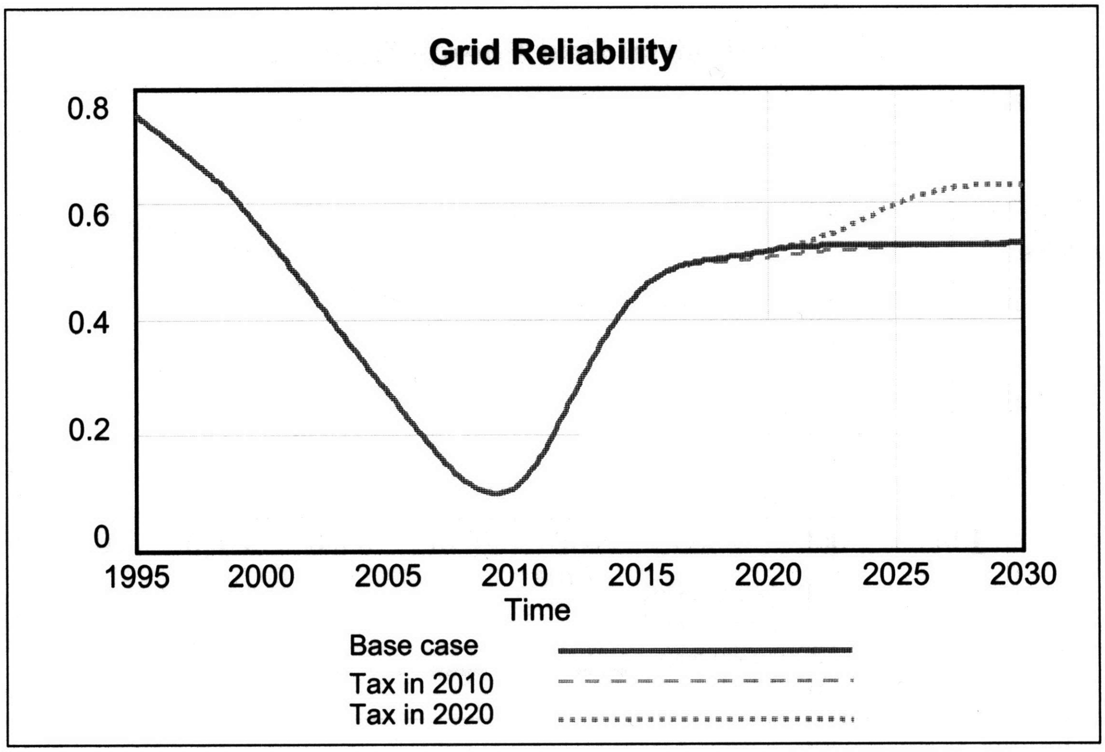


Figure 58: Grid reliability - tax in 2010, 2020

The outputs from the model under these cases show that a tax has less leverage in the system than a subsidy. This finding is logical since PV is already a more expensive option in most cases. Increasing the cost makes it further unattractive, but is less likely to change its position in the ranking of options. A subsidy can potentially make PV a more attractive choice relative to the existing options. This difference in leverage can be better seen in the comparison of temporary subsidies shown in Figure 59 and Figure 60.

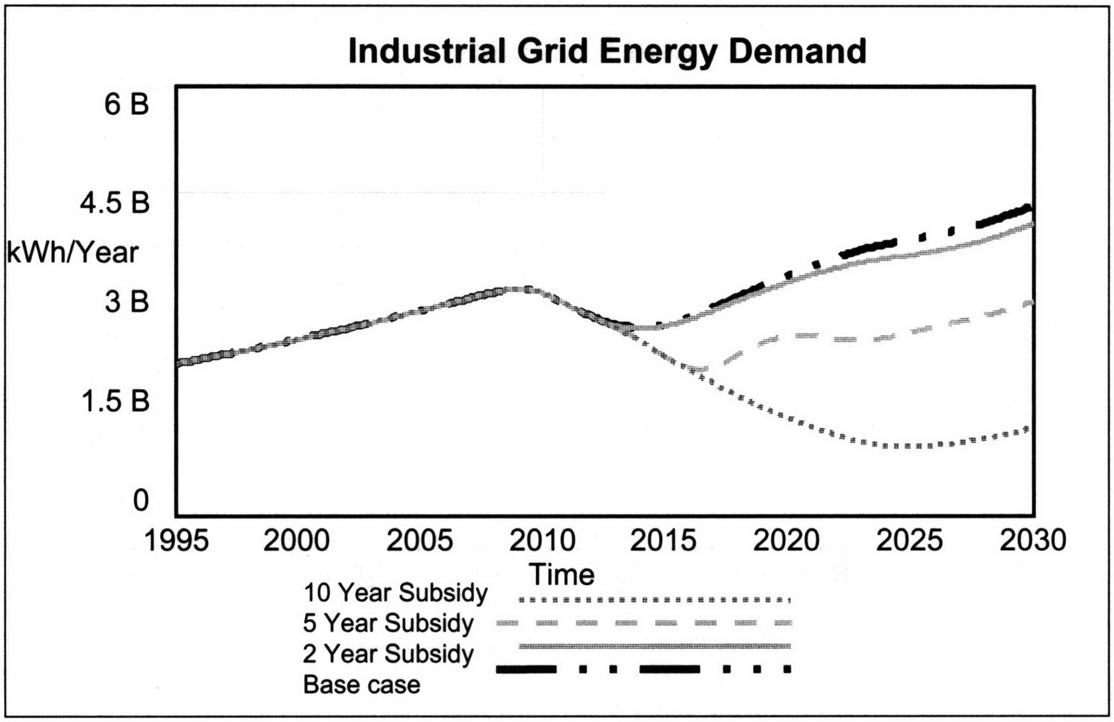


Figure 59: Industrial Grid Energy Demand for temporary subsidy scenarios

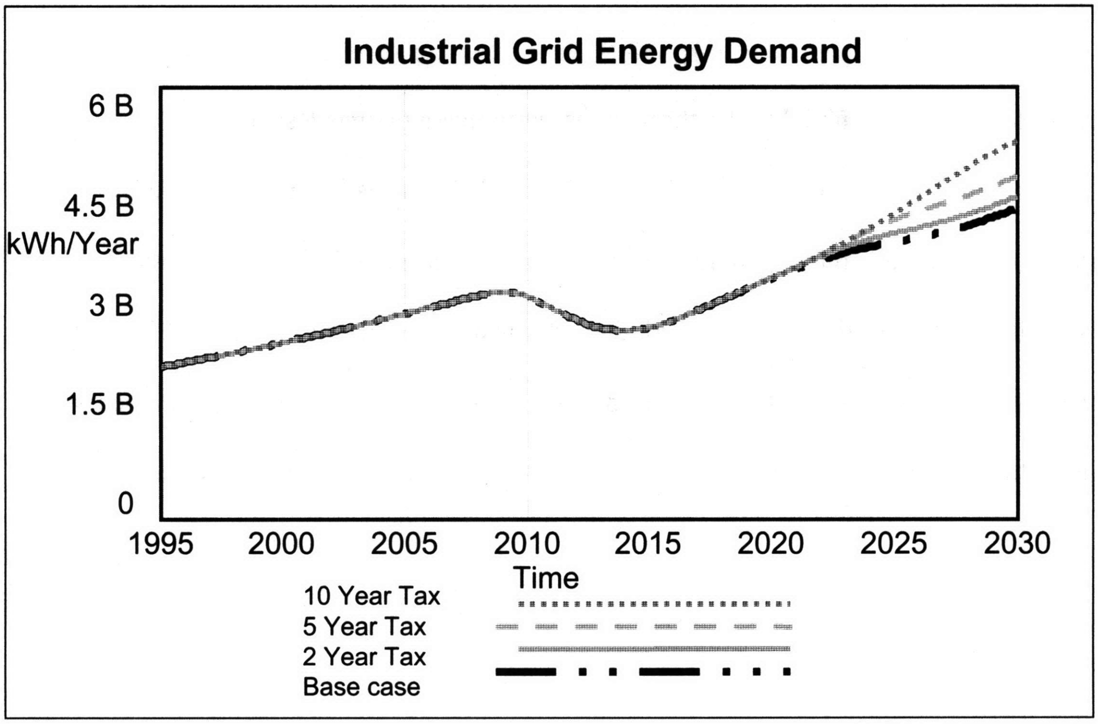


Figure 60: Industrial Grid Energy Demand for temporary tax scenarios

The primary implication of these scenarios is that lowering the cost of PV has a much greater impact than raising it. PV is already expensive when compared to other options so an increase in price does not have a great affect on its indicated market share. The policy implication of this finding is that planners who want to encourage PV can use subsidies to help this technology gain a share in the market, but ones who would like to block PV from entering should use policies other than taxation to discourage PV use.

The second set of runs focused on an additional feedback in the model, where the price of PV in Kenya drops due to the expanding market. There was still no assumption that the market in Kenya influences the world price, rather that the growing market reduces some of the inefficiencies in the internal market. This is achieved through adding a lookup function, where as PV installations grow the surcharge goes down (Figure 61).

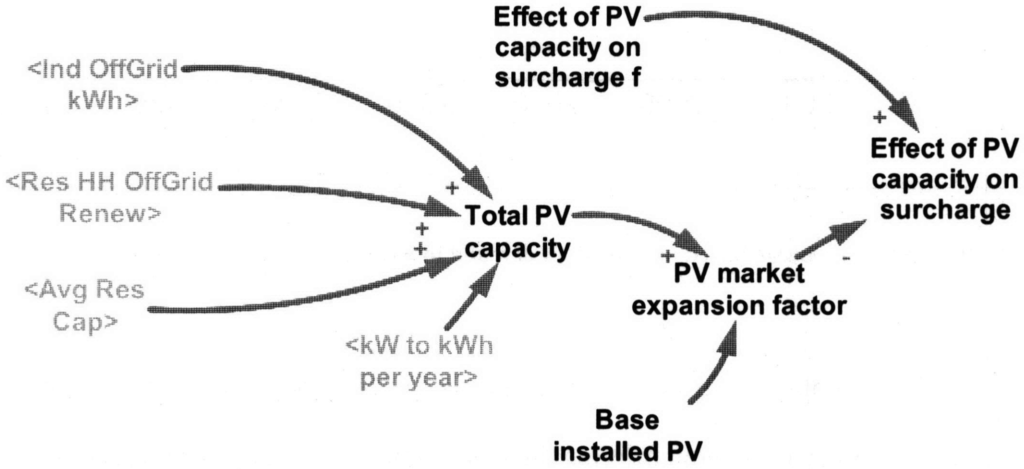


Figure 61: Added model component that reduces the surcharge on PV as the market grows

The effect of PV capacity on surcharge is added to the calculation of the price of residential and industrial PV. It creates a positive feedback where as the market grows, PV becomes less expensive and therefore more attractive. This creates a rapid decline in cost seen in Figure 62.

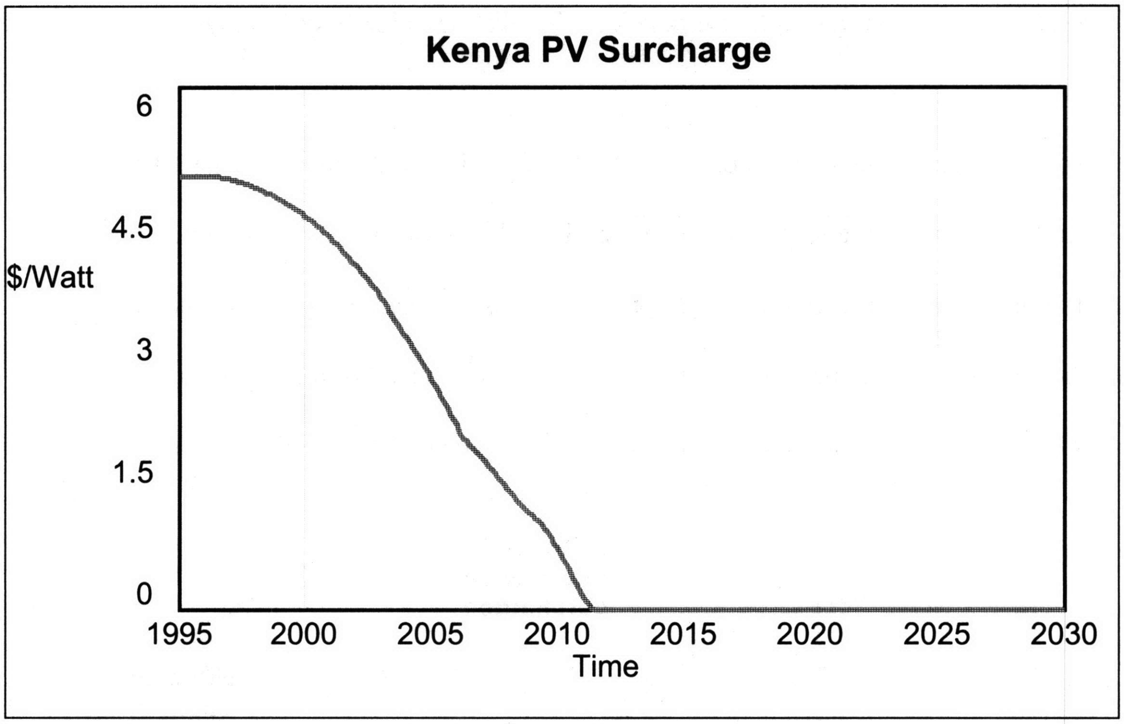


Figure 62: Drop in PV surcharge based on growth in demand in Kenya

The primary policy implication from this run is the need to consider ways of encouraging the market for technologies without offering direct subsidies. This type of approach is being tested in western Tanzania under a UN program to promote the photovoltaic market (Banks, Steel, and Kibazohi 2007).

In all case where the cost of PV falls, it creates a decline in the generation capacity demanded. Figure 63 shows the decline associated with the endogenous drop in PV price. Although there would likely be measures implemented to ensure the grid did not totally collapse, this trend shows that making off-grid PV more competitive in the market is a potential threat to the development of the grid.

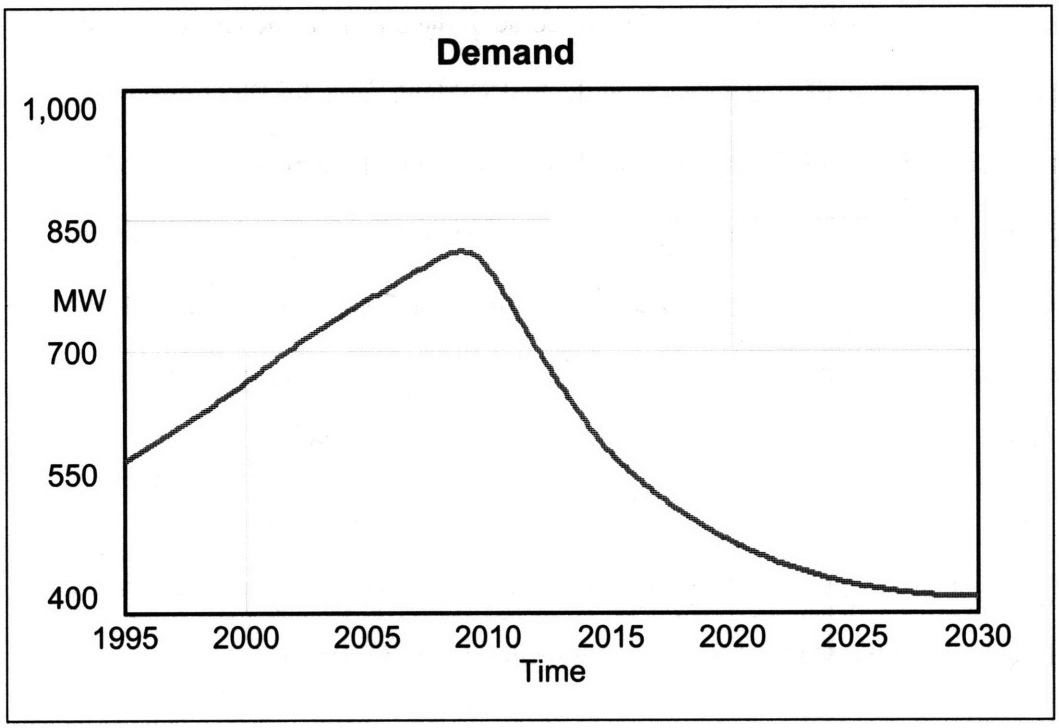


Figure 63: Grid capacity demand – Endogenous PV price drop

The price of PV is a leverage point that could be used by policy makers in two ways. First, if the goal is providing access to electricity for the greatest population, then lowering the cost of PV should expand the reach of electrification. Second, if the goal is to protect the grid as the primary power supplier, lowering the cost of PV is a threat to the development of the grid.

Future of Oil: *Price uncertainty*

The final scenario explored focused on the impact of the price of oil on the Kenyan system. As with PV, in the base case run the price of oil was found to be a key variable. Several options for changes in oil prices were explored in this scenario. First the model was run using the projected price of $25/barrel, which is the average value used by planners in Kenya. This was to illustrate why some of the planning choices were made in Kenya. The second set of model runs used the low and high cases for EIA projections of future oil prices (the EIA base case was used in the base run of the model). Both of these projections show increasing prices, with the rate of increase either low or high. Neither of these projections predicts oil prices above $100/barrel in 2008. Finally, I tested runs where the price of oil oscillated with a frequency of 10 years and had a peak of $100/barrel.

Table 14 summarizes the changes to the model under this scenario. All data inputs to the model are found in the Model documentation section of the Appendix.

Run	Base Equation	Scenario 3
Kenya planning	Projected oil price = GET XLS DATA('Kenya power model data.xls', 'Projected oil price' , 'A' , 'B2'), where B2 = base case	Projected oil price = 25 $/barrel
Projected oil price-Low	Projected oil price = GET XLS DATA('Kenya power model data.xls', 'Projected oil price' , 'A' , 'B2'), where B2 = base case	Projected oil price = GET XLS DATA('Kenya power model data.xls', 'Projected oil price' , 'A' , 'C2'), where C2 = low estimate
Projected oil price-High	Projected oil price = GET XLS DATA('Kenya power model data.xls', 'Projected oil price' , 'A' , 'B2'), where B2 = base case	Projected oil price = GET XLS DATA('Kenya power model data.xls', 'Projected oil price' , 'A' , 'D2'), where D2 = high estimate
Projected oil price-Cycle	Projected oil price = GET XLS DATA('Kenya power model data.xls', 'Projected oil price' , 'A' , 'B2'), where B2 = base case	Projected oil price = SIN WAVE with f=10, a = 25, 100

Table 14: Model changes under scenario *Price uncertainty*

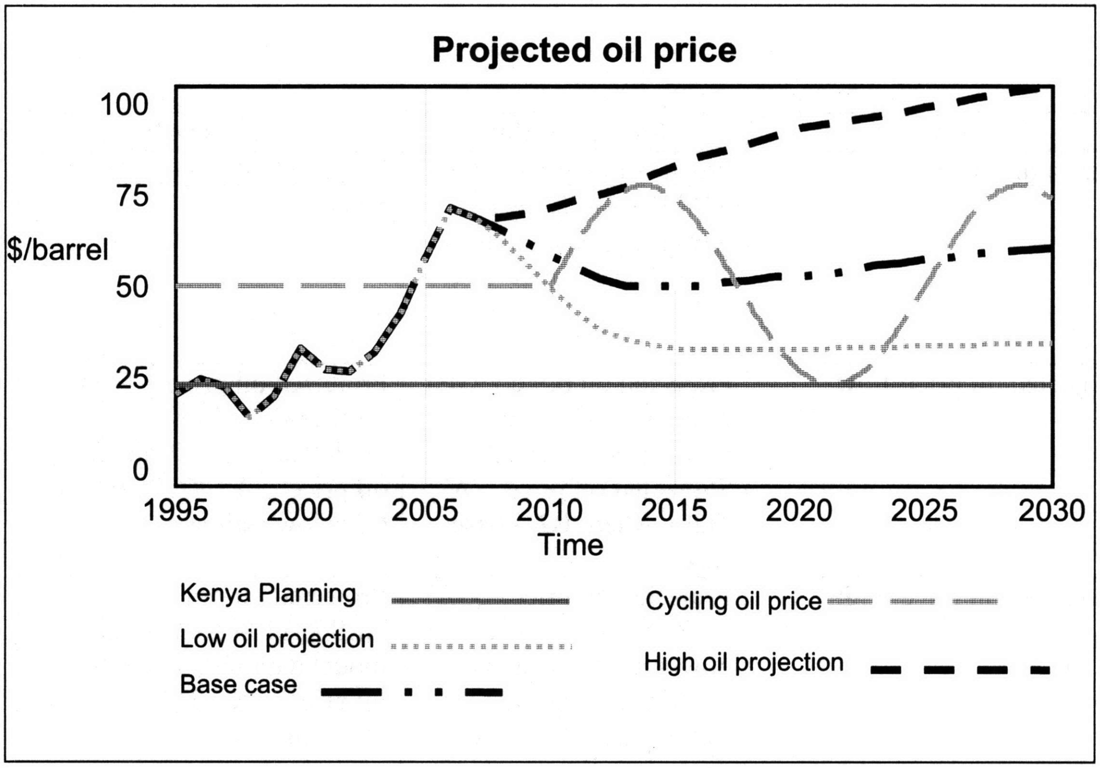


Figure 64: Projected oil price under scenarios

The results from these runs are not surprising. Low price oil should increase grid energy demand, while high price oil means more demand for off-grid sources (Figure 65).

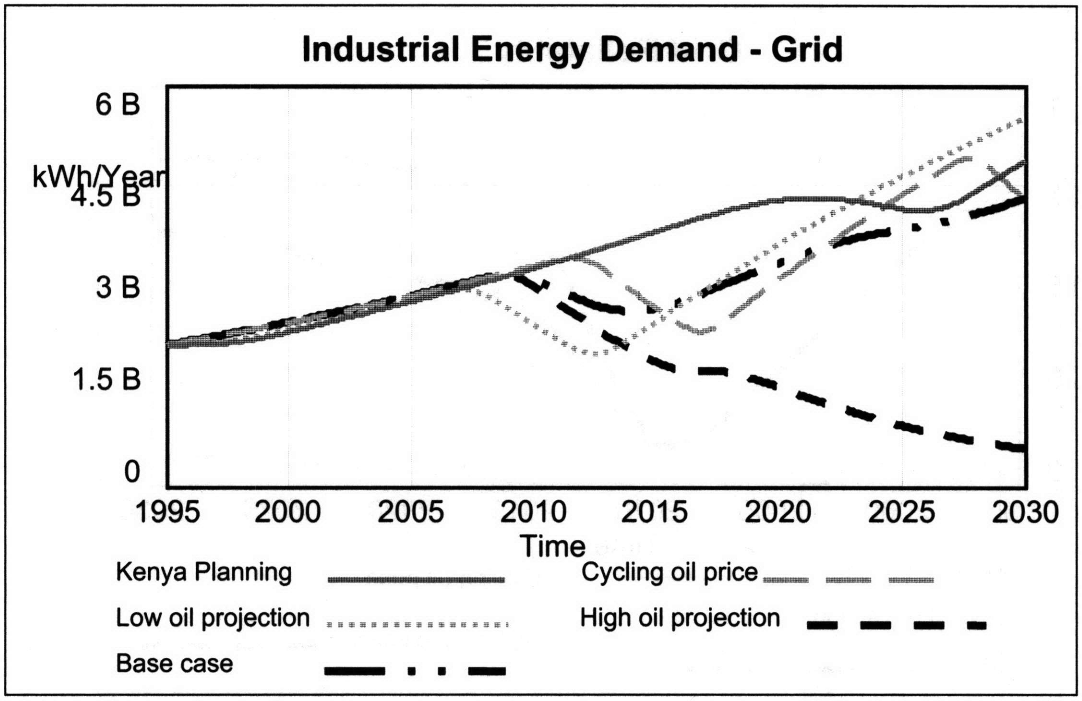


Figure 65: Industrial energy demand under oil scenarios

As was seen in previous runs of the model, when the grid is the dominant choice, the reliability is lower due to the pressure on the system capacity (Figure 66). It is easy to see why shifting oil prices has such an impact on outcomes by comparing electricity prices under the scenarios. Figure 67 shows the indicated prices for just the base case, Kenya planning, and high projections. Although price is only one of the components of the consumer decision-making, differences this large have a significant impact.

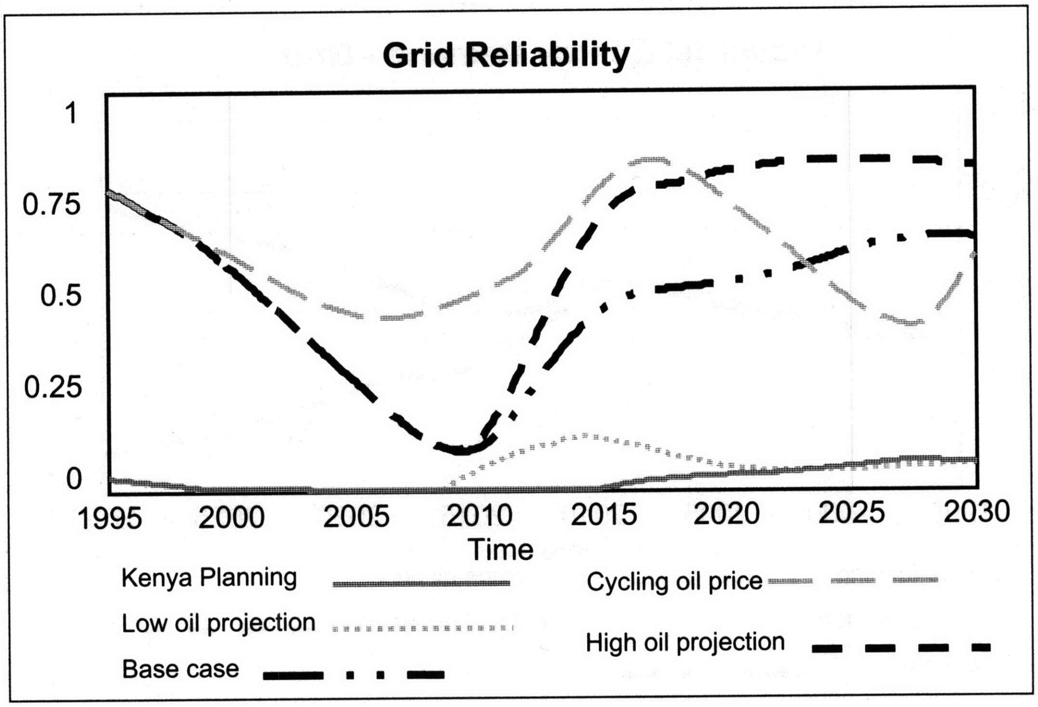


Figure 66: Grid reliability under oil scenarios

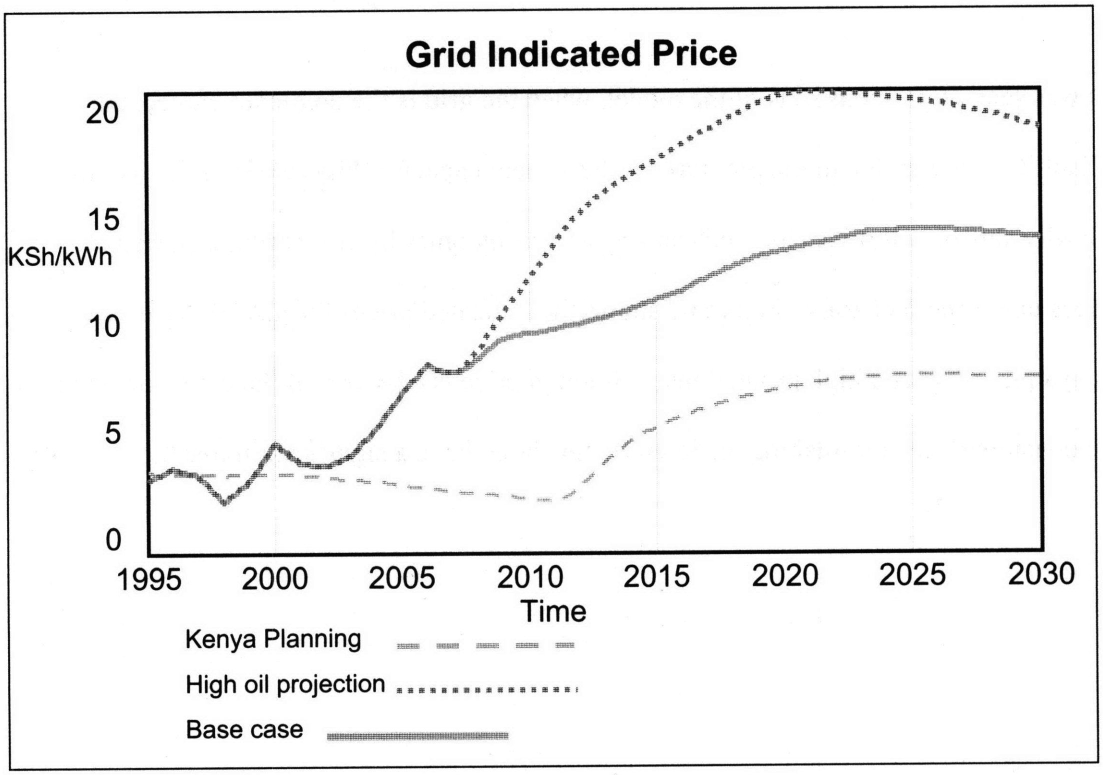


Figure 67: Indicated grid price under oil scenarios

The primary policy implication from the runs focused on oil prices is that the price of grid electricity is very closely tied to the world oil price. Since Kenya has no control over world prices, this is an extremely risky position to be in. Future planning for Kenya currently focuses on expanding thermal power generation and imports (as well as limited expansion of geothermal power). Imports from Uganda and Tanzania are already questionable, given that both countries have had power shortages in 2005-2006. For future planning KPLC should consider ways to decouple grid prices from oil prices through expansion of other sources. If this is not possible, planning should include this uncertainty and consider options for alternative development based on long term price trends.

General policy implications from scenarios

The three scenarios were chosen for their potential as leverage points in the development of the Kenyan power system. The findings from the scenario analysis show:

- Improvements in KPLC may benefit the households connected, but will not impact the overall development of the grid
- Policies to reduce the price of PV could have a great impact on the market for off-grid and grid power. Taxes and added costs will have less of an impact, apart from the revenue that could be generated to the government.
- Grid generation expansion should focus on decoupling electricity prices from oil prices or determine ways to manage the uncertainty in this key input.

Generally, the scenarios show the grid is in a precarious position. There are several leverage points which could shift the balance away from grid being the dominant choice.

As discussed in the introduction to the case study selection, at the time of writing Kenya's political stability was tested by a contentious election and ethnic violence across the country. Although the country was able to negotiate a power-sharing settlement, there is likely to be even less faith in the government in the near future. For infrastructure development, this may be a further push towards decentralization and self-generation. For industrial and residential consumers, off-grid generation might also now be a way to hedge against further political disruption. Given the timing of these events they were not included in the model, but should be considered in future work and follow-up interviews.

Discussion

The goal of building the system dynamics model was test the theory that there was no clearly dominant choice in the market and that there were conditions that could create a "death spiral" for the power company. On the first point, the model shows the theory was basically incorrect. I had expected that there was no clearly dominant choice, but in most cases there is. Although the best option does change over time, in most periods there is a clear winner for both industrial and residential consumers (though not the same choice).

Given this, the second theory is supported by the model. There are additional scenarios that could be explored looking at economic growth, new technology inputs, and a greater range of price projections. The scenarios discussed in this section were in part chosen because of the realism of these cases. KPLC may not be able to reach its capacity targets, but it is currently trying to expand its connection capacity. The scenarios involving PV prices do not change the learning curve or make any assumptions about technological change. Similarly, the oil prices scenarios are well within the current projections and do not assume new technology changes or scarcity costs.

Since this study began, Kenya has started to look seriously at biofuels and biomass gasification technologies. It remains to be seen if this technology is going to be something they will be able to develop expertise in, as they have with geothermal technology. The model was designed with the renewable subscript as generic so that it can be expanded to include new technologies. If biomass and biofuel options are added to the model, it would also need to account for the uncertainty in the effects of large-scale fuel production. Also since this study began, there has been a push to add subsidies added for several non-solar renewable energy sources. This may reflect a government stance against PV and could have a significant impact on the dynamics of development if many of the sources are primarily off-grid.

The model not only gives insight into the important leverage points in the system, it also provides a tool for future analysis. It can be expanded to include a wider range of technologies and policy options and can be adapted to fit other countries with similar power system development dynamics. For planning purposes, the work now is in determining what is the end goal for the system and testing what policies will generate development along that path.

References

Banks, D, and K. Steel, O. Kibazhoi. 2007. "Transformation of Rural Photovoltaic (PV) Market in Tanzania URT/03/G31/A/1G/99 Mid-Term Evaluation". UNDP. Available online: www.solarmwanza.org.

Kenya Power & Lighting Company. 2005. Least Cost Development Plan. Internal document.

Steel. K. 2003. "Technical and Financial Feasibility of Renewable Energy Mini-Grid Systems in Northern KwaZulu-Natal" Unpublished M.Eng.Sci.thesis. The University of Melbourne. Melbourne, Australia.

Conclusions and Future Research

The findings from the ethnographic study and model have implications for electrification planning in Africa and for understanding the challenges of working with problems within a developing country context. This work is intended to be a descriptive study of the feedback between decision-making among stakeholders in the power system and its development. Ideally, this represents an area of growth for the study of engineering systems, as there is a large body of potential research in this topic.

The primary policy implications discussed in the previous section were:

1. Limited gains from focus on residential connections performance
2. When reliability is included in the decision process, small changes in the price of PV can have a large effect on grid system development
3. Grid generation expansion needs to focus on decoupling electricity prices from oil prices or determine ways to manage the uncertainty in this key input

The overall finding from this research was that there is a potential shift from a centralized power system to a decentralized one. Energy planners should focus on the ideal end state for the system architecture and use these policy levers to determine a pathway to that goal.

Contributions

This research has both academic and applied contributions. On the academic side, it extends the range of power system modeling to include qualitative factors found in an

African environment. These factors include the addition of reliability and availability of the electric power grid and the biases in decision-making, which differ from those in industrialized countries. Within the field of engineering systems, this is a study of a large-scale, socio-technical system, where the social and behavioral complexity is currently less well understood than the technical complexity. This research applied an ethnographic lens to understanding the relationships amongst stakeholders, but then translated that into a quantitative model. This method could be applied in a range of development oriented projects within engineering systems, in order to better understand the relationship between technical systems and their users.

While the model clearly has direct application in Kenya, it was designed with flexibility to be expanded to include other countries and regions. The basic feedbacks were kept at a high level so they are a general approximation of an African power industry and the technology options are subscripted so they can be adjusted to fit the energy mix in other countries. The findings from the Kenya study could be adapted to fit many other countries.

Future research

The conclusions from this research leave a number of questions still unanswered. As this was intended as a base study, there is significant future research that could build from both the model and the general approach. As with the contributions, there are both academic and applied areas for extending the work.

On the academic side, there is great room for work in refining qualitative data collection methods for system dynamic models of development projects. For this project, the range of power system data and interview data available defined the boundary and scope of the model, but in the future it would be interesting to approach the data collection from the needs of a more complete model. If the boundary were to be defined first, then the range of data could be better targeted.

In the field of system dynamics, it would also be beneficial to develop modules for development applications, both energy and other sectors. At the macro level, these modules could potentially include the dynamics of international lending, debt servicing, and political risk in financial decision-making. On a smaller scale, it would be beneficial to have modules to describe decision-making under poverty constraints and the threshold point when a household passes out of extreme poverty.

An additional area of future research is to compare the dynamics seen in this model with the development of other infrastructure systems, both in Kenya and other regions. This model was partly based on the evidence from the telecom sector in Kenya and it would be interesting to see if the pattern holds for water systems or gas distribution systems. The model could also be tested using similar data from the East African region or other African countries with similar electricity problems, such as Nigeria or Ghana. Research in this direction would add to the knowledge of general development dynamics.

Africa has a nascent electric power system. Instead of thinking of it as a backward or simplistic version of an industrialized grid, we need to think of it as a complex system where the architecture is not already determined. This is an exciting opportunity for the study of engineering systems. Instead of determining what should have been done, or what needs to be done now that problems have arisen, we are able to look at the possibility of what *can* be done. Policy makers still have options in determining the course of development. The methods for dealing with uncertainty are the same, but development problems offer the potential to study systems from the ground up. The study of engineering systems has largely focused on managing uncertainty in existing complex technical systems and this research points to the opportunities for analyzing complex systems in development.

Appendices

Terms and abbreviations

CDM	Clean Development Mechanism
EAMP	East Africa Master Electrification Plan
EDM	Ethnographic Decision Modeling
ERB	Electricity Regulatory Board
GOK	Government of Kenya
IPP	Independent Power Producer
ITDG	Intermediate Technology Development Group
Jua Kali	Casual manufacturing and service industry
KenGen	Kenya Generating Company
Kenya CBS	Kenya Central Bureau of Statistics
KPLC	Kenya Power and Lighting Company
KTDA	Kenya Tea Development Authority
kWh	Kilowatt-hour
LCDP	Least Cost Development Plan
MOE	Ministry of Energy
MW	Megawatt
PV	Photovoltaic
SHS	Solar Home System
Telkom	Kenya telecommunications provider

Interview guidelines and data

COUHES authorization (English)

CONSENT TO PARTICIPATE IN INTERVIEW

Study: Investment and growth in Kenya's electric power system

You have been asked to participate in a research study conducted by Katherine Steel from the Engineering Systems Division at the Massachusetts Institute of Technology (M.I.T.). The purpose of the study is to analyze investment and growth in the Kenyan electric power system using information provided by stakeholders in the system. The results of this study will be included in Katherine Steel's PhD thesis. You were selected as a possible participant in this study because you are involved in the supply and/or consumption of electricity in Kenya. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

- This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time. We expect that the interview will take a maximum of one hour.
- You will not be compensated for this interview.
- Unless you give us permission to use your name, title, and / or quote you in any publications that may result from this research, the information you tell us will be confidential.
- We would like to record this interview on a digital recorder so that we can use it for reference while proceeding with this study. We will not record this interview without your permission. If you do grant permission for this conversation to be recorded, you have the right to revoke recording permission and/or end the interview at any time.

This project will be completed by June 2007. All interview recordings will be stored in a secure work space until one year after that date. The recordings will then be destroyed.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

☐ I give permission for this interview to be recorded on audio cassette.

☐ I give permission for the following information to be included in publications resulting from this study:

☐ my name ☐ my title ☐ direct quotes from this interview

Name of Subject:

Signature of Subject ______________________________ Date __________

Signature of Investigator ______________________________ Date __________

If you have questions or concerns, please contact:
Katherine Steel
ksteel@mit.edu
0724 076336 (Kenya)
+1 617 5198917 (USA)

If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143b, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253-6787.

COUHES authorization (Swahili)

IDHINI YA KUSHIRIKISHWA KAMA MHOJIWA

Mada ya Utafiti: Uwekezaji na Maendeleo ya Mfumo wa Uenezaji wa Nguvu za Umeme Nchini Kenya

Unaombwa kushiriki katika utafiti unaofanywa na Katherine Steel ambaye ni mkufunzi katika kitengo cha Mifumo ya Uhandisi katika Chuo cha Teknolojia cha Massachusetts (MIT) kilichoko Marikani. Madhumuni ya utafiti huu ni kuchanganua maswala ya uwekezaji na maendeleo ya mfumo wa uenezaji wa nguvu za umeme kati ya wadau wanaohusika nchini Kenya. Matokeo ya utafiti huu yatachangia uandikaji wa tasnifu ya shahada ya PhD ya Katherine Steel. Sababu ya kuchaguliwa kwako kama mhojiwa hasa ni kuwa wewe unahusika, kwa njia moja au jingine, katika usambazaji na/au utumiaji wa nguvu za umeme nchini Kenya. Wapaswa kusoma ujumbe ufuatao na kuuliza lolote usiloelewa kabla ya kuamua kujibu au kutojibu maswali ya utafiti huu.

Utafiti huu ni wa hiari. Kwa hivyo, uko huru kutojibu swala lolote katika hojaji hii au hata kutamatisha kuhojiwa iwapo hutaki kutenda hivyo. Yakisiwa kwamba shughuli ya kukuhoji itachukua muda wa saa moja.
Hamna malipo kwa wahojiwa.
Iwapo hutatoa kibali cha kulitaja jina au cheo chako, au hata kunukuu maoni au hisia zako katika vitabu, matini au majarida yatakayonukuu matokeo ya utafiti tunaonia kufanya, basi kila utakalowasilisha litachukuliwa kuwa siri yako na wala halitachapishwa.
Twanuia kuhifadhi majibu yako katika kinasa-sauti ili kurahisisha urejeleaji wa hoja zako tunapoendelea na uchanganuzi na vilevile uandishi wa matokeo ya utafiti. Hata hivyo, hatutanasa sauti tunapokuhoji iwapo hutatoa kibali. Hata utoapo kibali cha kutumia kinasa-sauti tunapokuhoji, una haki ya kutamatisha shughuli hiyo iwapo utapenda.

Mradi huu utamalizika mwezi Juni, mwaka wa 2007. Hojaji zote zitahifadhiwa kwa muda wa mwaka mzima kutoka wakati utafiti utakapokamilika. Hapo baadaye hojaji hizo zitaharibiwa.

Naelewa na yote yaliyodokezwa hapo juu. Nishafahamu kila linipasalo kufahamu kwa njia sahihi na nimekubali kushiriki katika utafiti huu. Pia nimepata nakala ya matini (fomu) hii.

☐ Nimekubali hojaji hii inaswe katika katika kinasa-sauti.

☐ Nimetoa kibali cha kunukuu ujumbe nitakaotoa katika majarida, vitabu na matini nyinginezo zitakazoibuka kutokana na utafiti huu.

☐ Jina langu. ☐ Cheo changu ☐ Nukuu za moja kwa moja kutokana na uhojaji huu.

Mada:

Sahihi ya Mada________________________Tarehe___________

Sahihi ya Mtafiti_______________________ Tarehe___________

Iwapo una maswali au tashwishi yoyote tafadhali wasiliana na:

Katherine Steel
ksteel@mit.edu
0724 076336 (Kenya)
+1 617 5198917 (USA)

Iwapo kwa vyovyote vile unahisi umetendewa visivyo, au iwapo una maswali kuhusu uhojiwa wako tafadhali wasiliana na Mwenyekiti wa Kamati ya Ushirikishaji wa Binadamu kama Vipengee vya Utafiti katika Chuo cha MIT, Chumba E143b, 77 Massachusetts Ave, Cambridge, MA 02139, Simu: 1-617-253-6787.

Translated by: Albert Gituku, Kenya Leadership Institute, Nairobi

Interview guideline questions

Group 1: Residential electricity consumers

1. How long have you been connected to the grid? Can you tell me about when power first came to this area?
2. What is your average electricity usage per month? What appliances do you use mostly? What hours of the day? For how long?
3. Since being connected, have you increased your electricity use? If so, what appliances have you added? If not, why? Cost of usage? Cost of appliances?
4. How often do you have power cuts/blackouts? Can you tell me about what happens when the power goes out?
5. Do you have a back-up power supply? What factors did you consider when deciding whether or not to purchase back-up power?

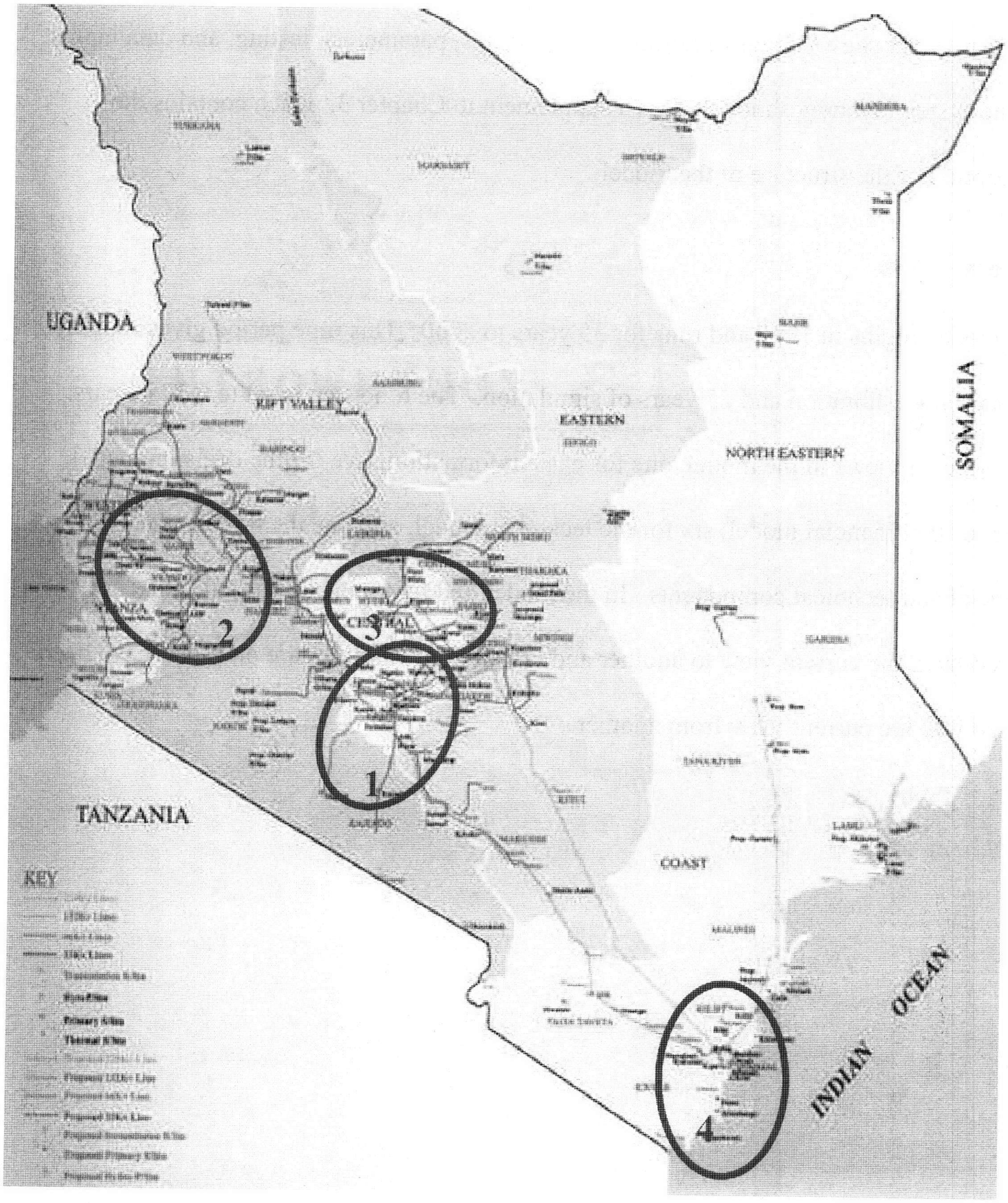
Group 2: Industrial/commercial electricity consumers

1. What is your average electricity usage per month? What parts of your business require electricity? What hours of the day? For how long?
2. Since being connected, have you increased your electricity use? If so, what appliances have you added? What factors did you consider in deciding whether to increase your electricity use?
3. How often do you have power cuts/blackouts? Can you tell me about what happens when the power goes out?
4. Do you have a back-up power supply? What factors did you consider when deciding whether or not to purchase back-up power?

Group 3: Off-grid generator dealers (solar and diesel systems)

1. How many systems have you sold in Kenya? Can you tell me about how your sales have changed over the past decade; have sales increased, decreased, or stayed the same?
2. Who are your primary customers? Residents? NGOs? Industry?
3. How much do your systems cost? (Capital cost only) What is the estimated cost of operating one of your systems?
4. Can you tell me the main reason customers give for purchasing the system?

Map of Electric Power Grid and Regions of Study



Regions of study:

1. **Nairobi:** CBD, suburbs, Limuru, Ruira, Magadi
2. **Western:** Kisumu, Mumias, Webuye, Chemelil, Nandi, Kericho
3. **Central highland:** Nyeri, Thika, Kianyaga
4. **Coast:** Mombasa CBD, Diani, Nyali, Kilifi

Model documentation

This Appendix shows documentation of all variables, parameters, testing, and data inputs for the system dynamics model. It is a supplement to Chapter 3, which contains the description of the structure of the model.

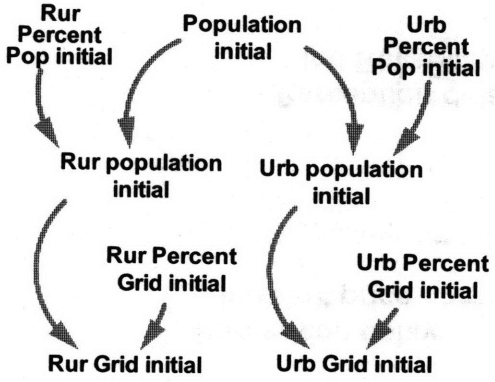
General notes

The model begins in 1995 and runs for 35 years to 2030. This time period gives roughly 10 years for calibration and 25 years of simulation. The time step is set to 0.125 Years. There are 16 views in the model, one for basic information, five for the decision model, three for the financial model, six for the technical model, and one the bridges the financial and technical components. In the model, red font indicate variables that are passed from the current view to another and orange font variables are ones that have been passed into the current view from another.

Model structure

Basics

Initial settings (1995 values)



Gen cap initial

TLine cap initial

Urbanization initial

Grid Res Base unit price initial

Grid Ind Base unit price initial

Assumed values

Avg household

Avg Res Cap

Projected PV price

Kenya PV surcharge

Residential Baseload

Industrial Growth

Avg Ind Cap

Avg Res kWh

Projected oil price

Projected Percent Population in poverty

Gen Cap desired margin

Conversion factors

kWh to GWh

kW to kWh per year

World oil to Kenya oil

W to kW

kW to MW

Real exchange rate

Calibration data

Res cons hist

Res Grid price hist

Ind Grid price hist

TSub Cap hist

TLine Cap hist

Demand hist

Ind cons hist

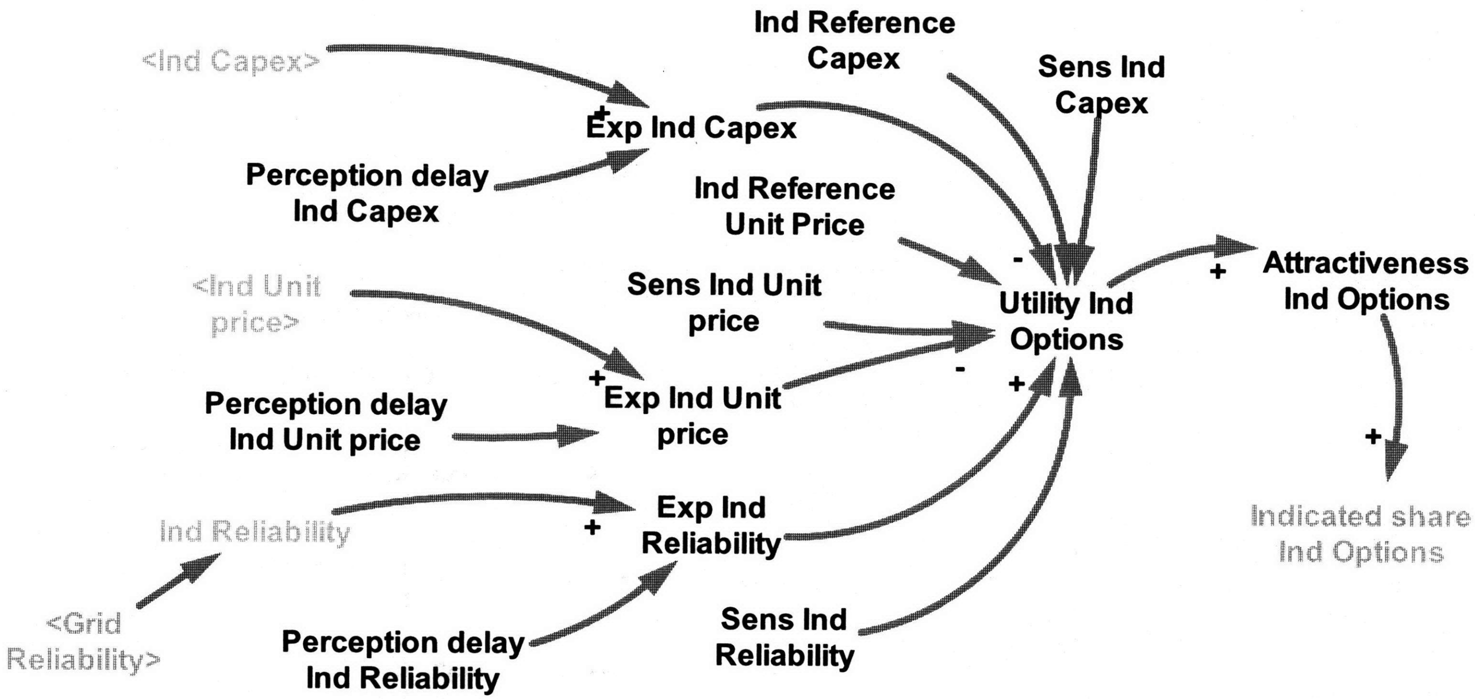
Dieselprice hist

Gen Cap hist

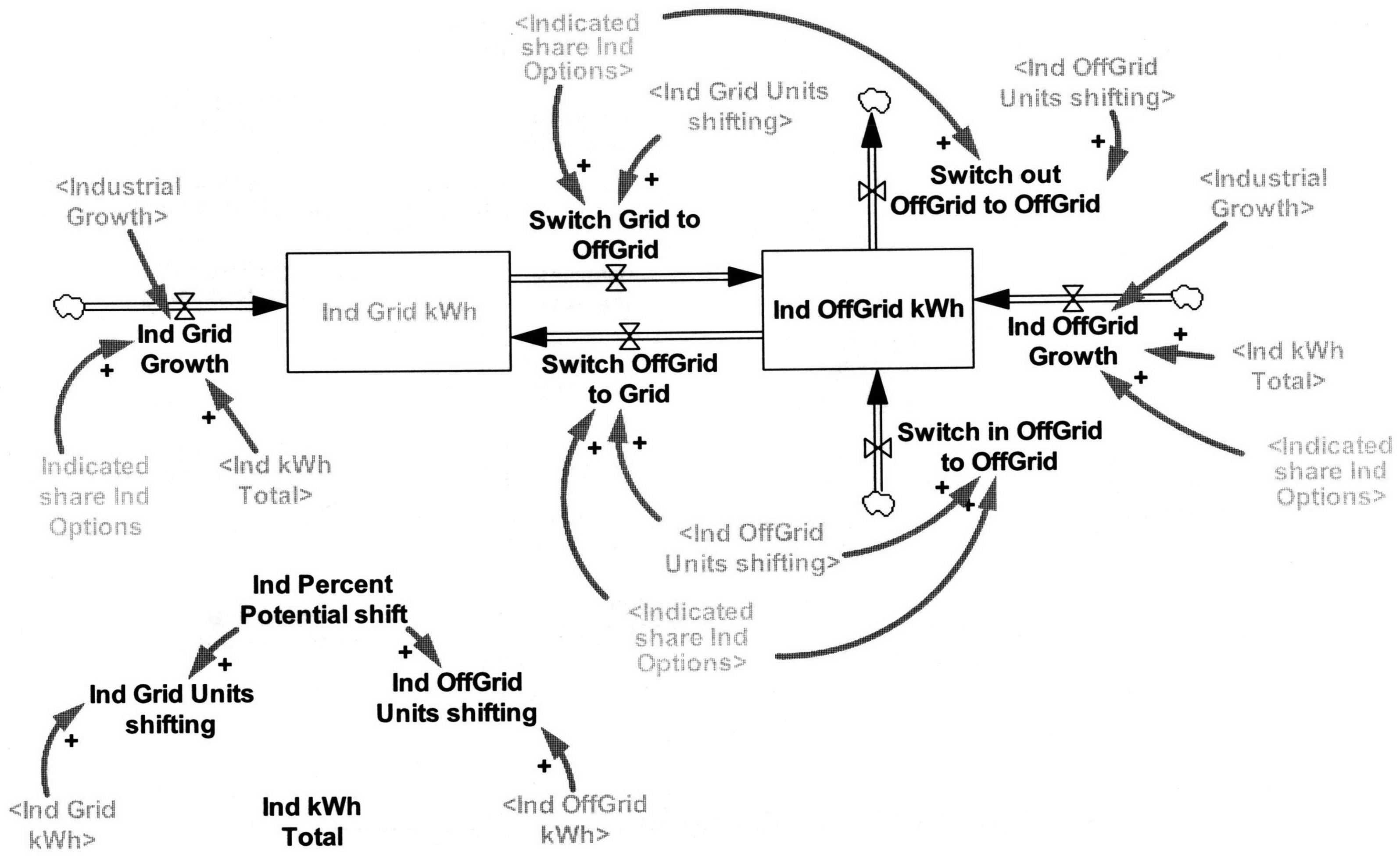
Projected LCDP

Base oil price KPLC

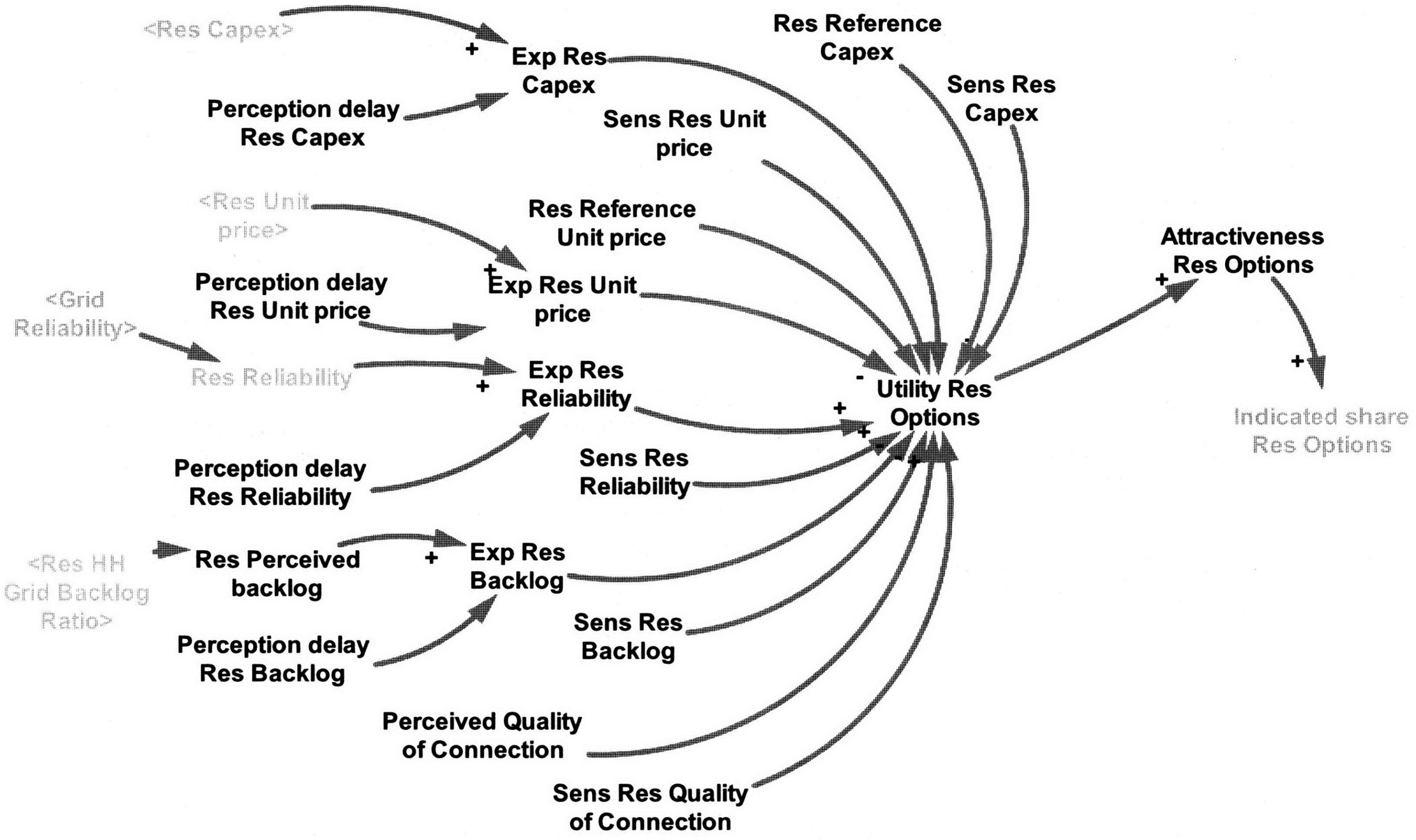
Industrial Decision Model - Logit function



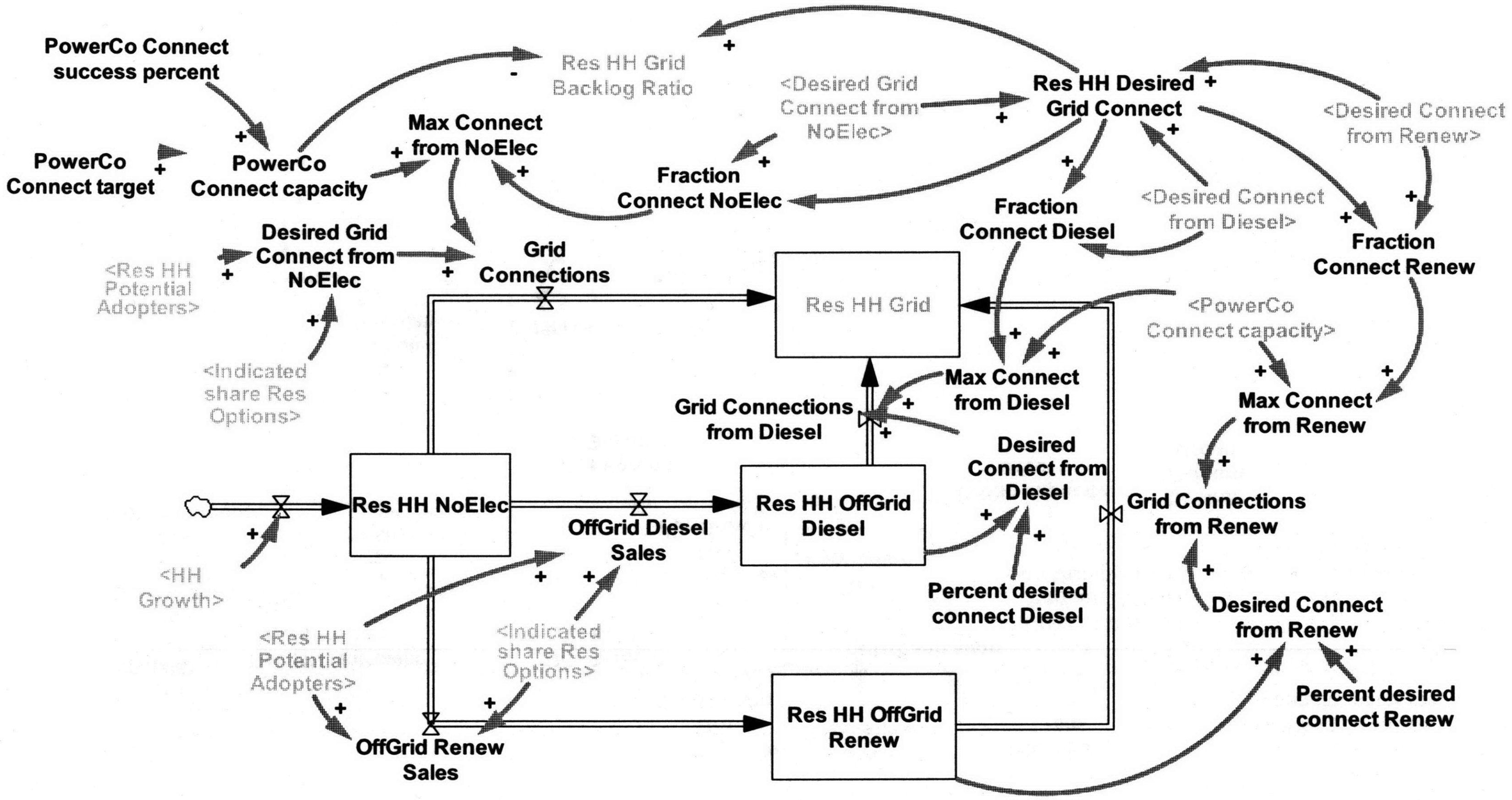
Industrial Decision Model - Customer allocation



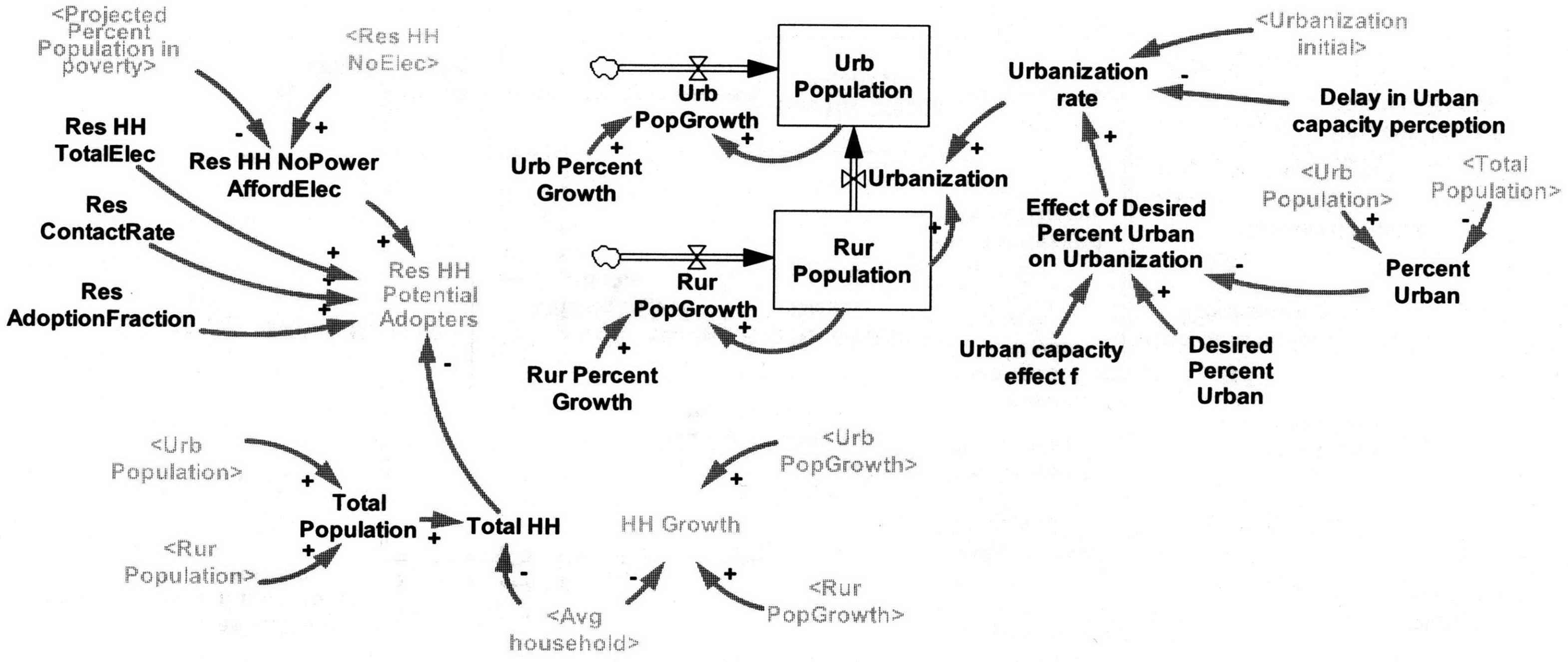
Residential Decision Model - Logit function



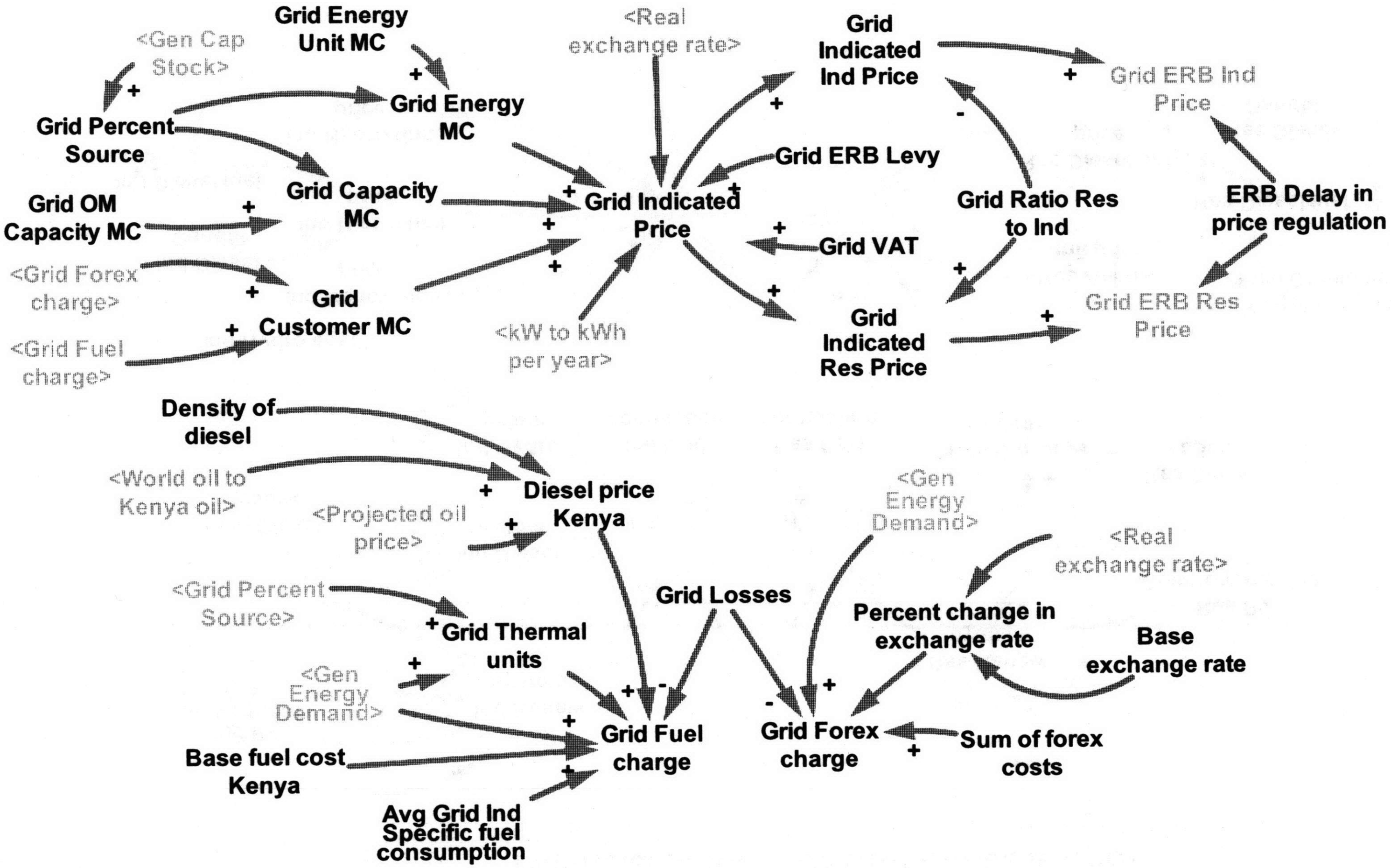
Residential Decision Model - Customer Connections

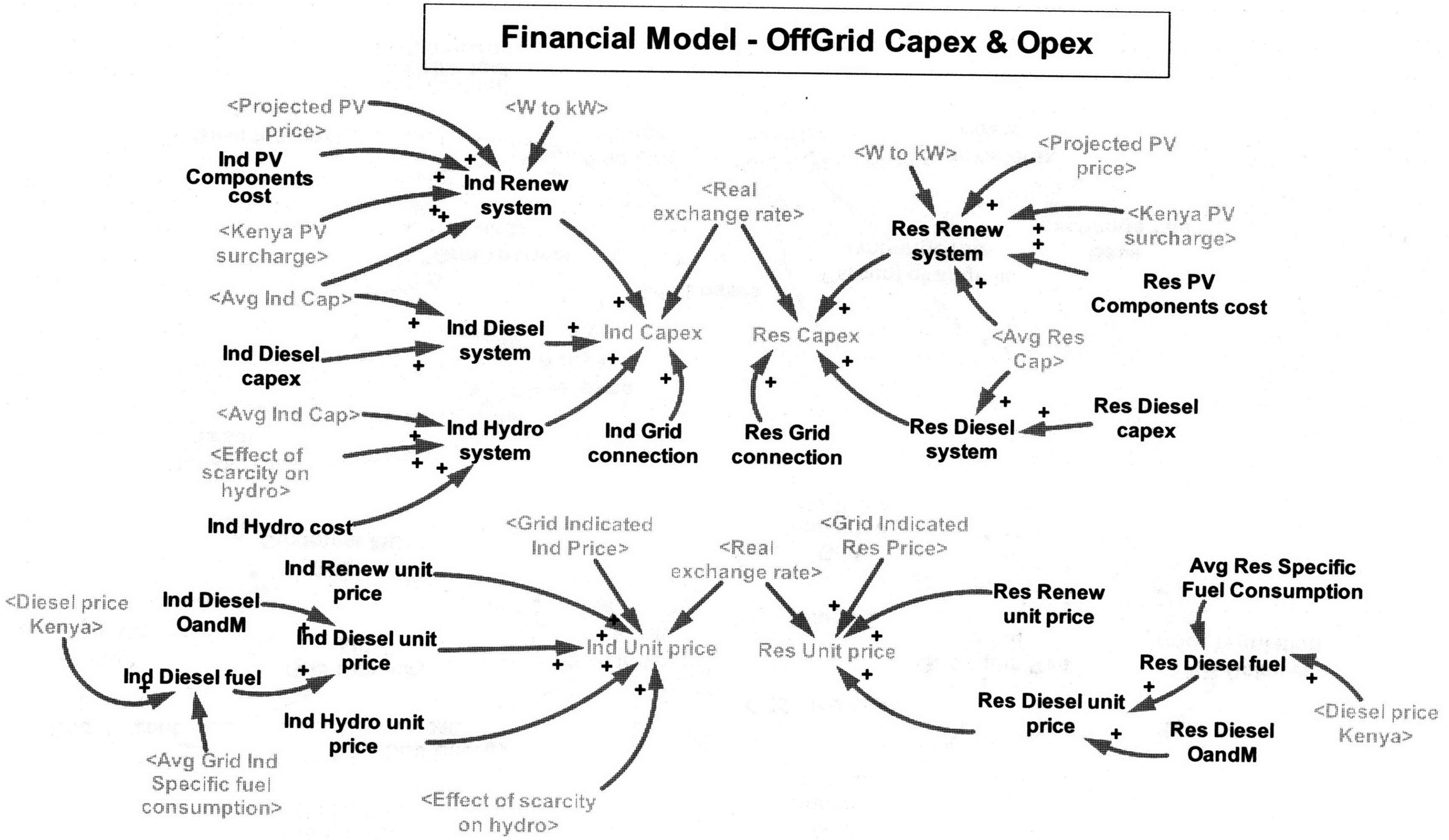


Residential Decision Model - Customer Demographics



Financial Model - Grid Capex & Opex




Financial Model - OffGrid Capex & Opex
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Ind Diesel capex
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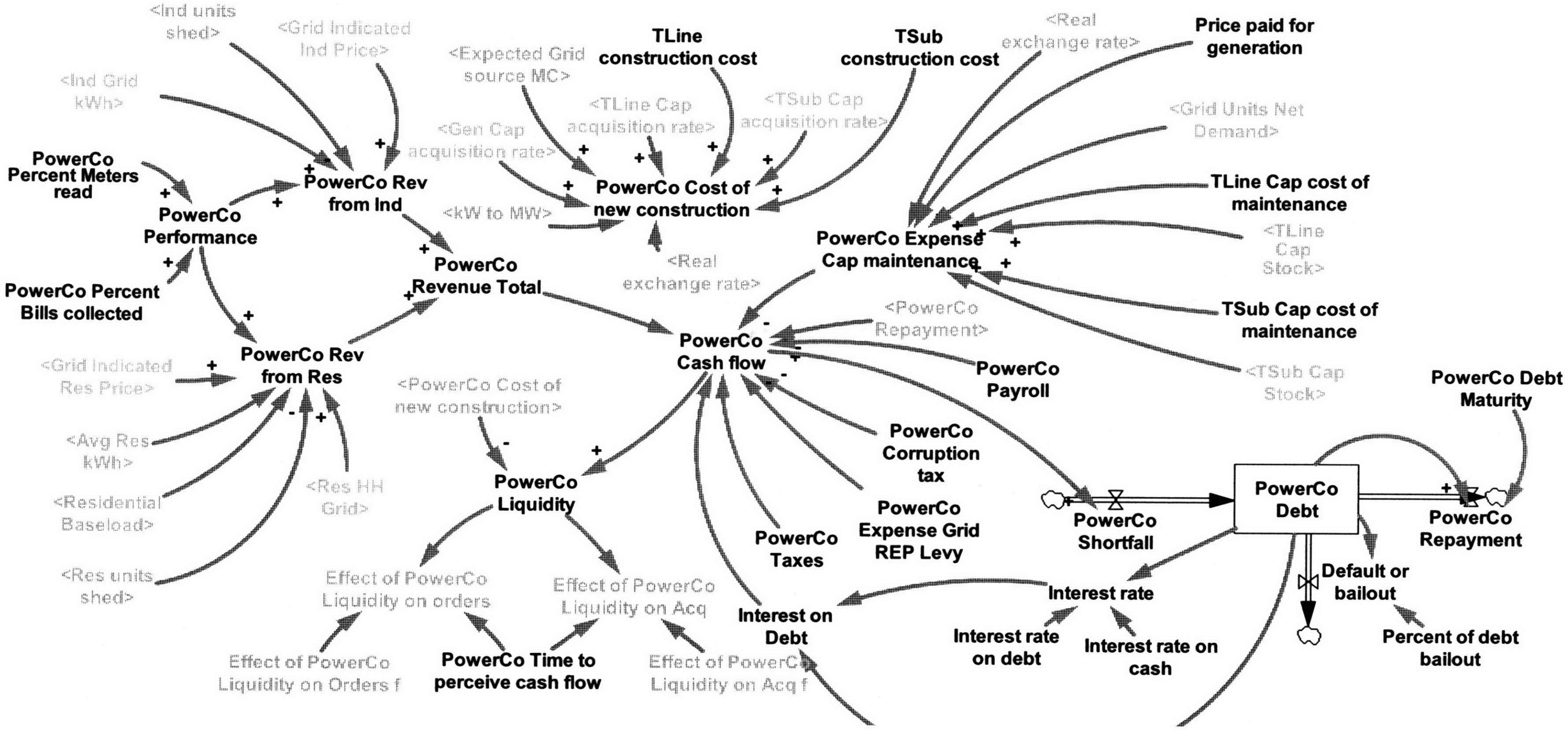
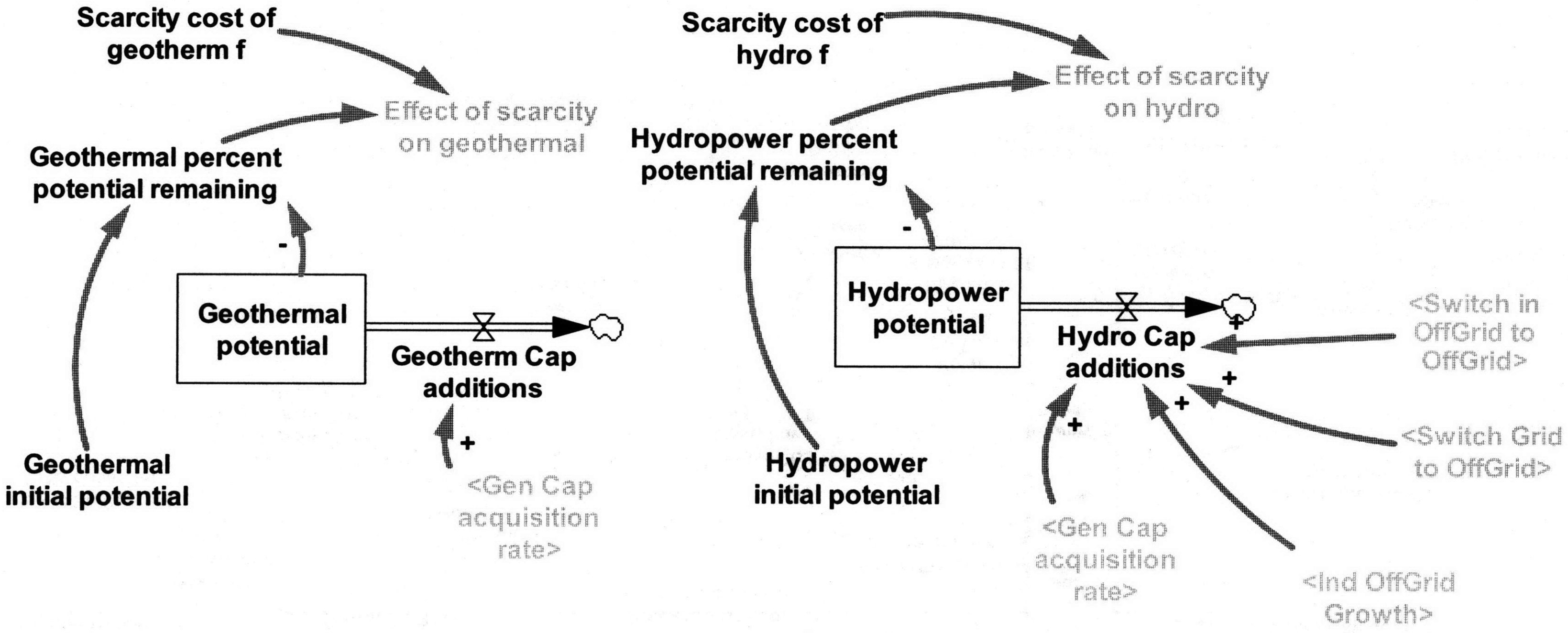
Ind Unit price
Res Unit price
Res Renew unit price
Avg Res Specific Fuel Consumption
Res Diesel fuel
Res Diesel unit price
Res Diesel OandM
<Diesel price Kenya>
+

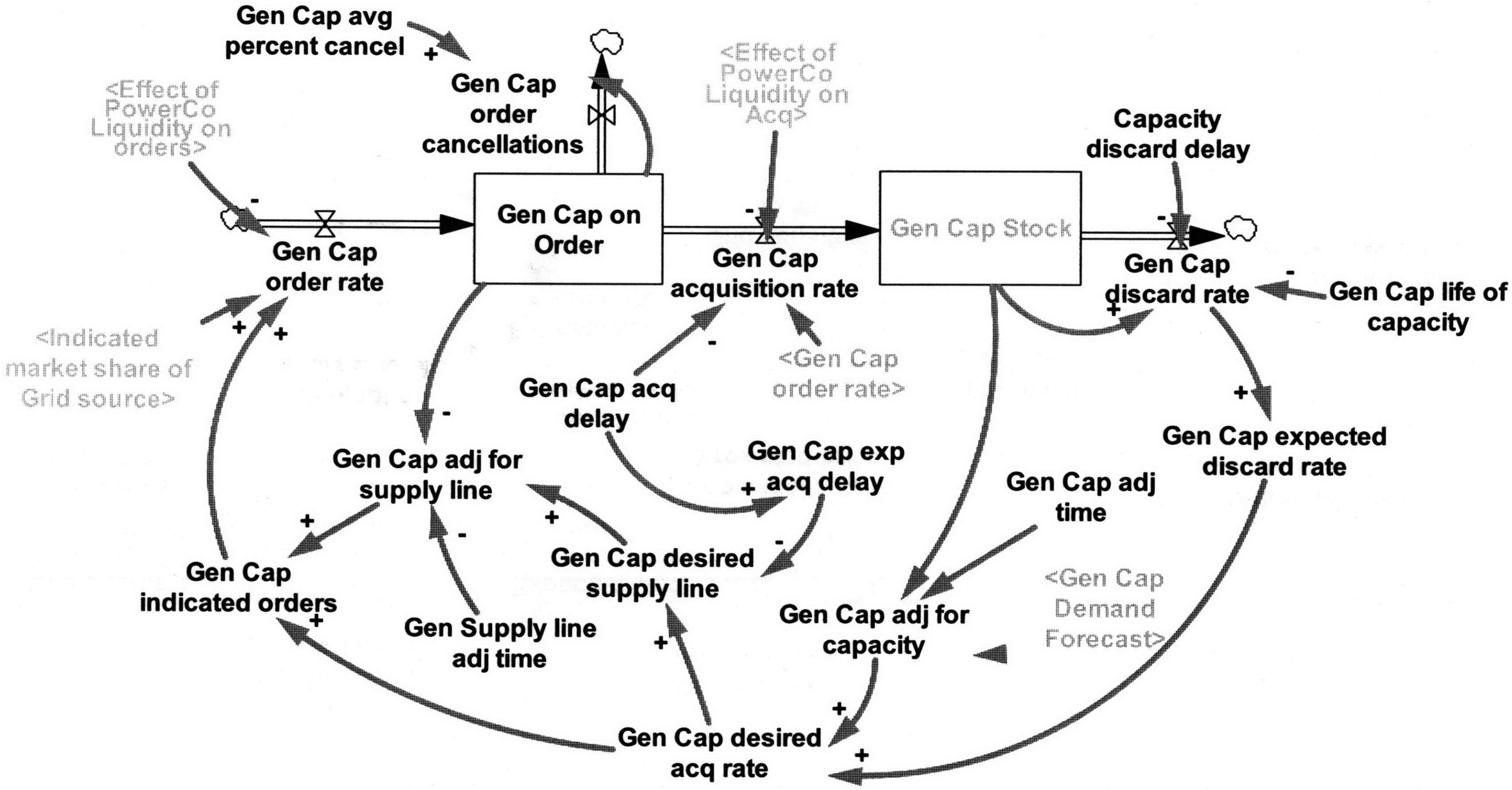
Financial Model - PowerCo Liquidity



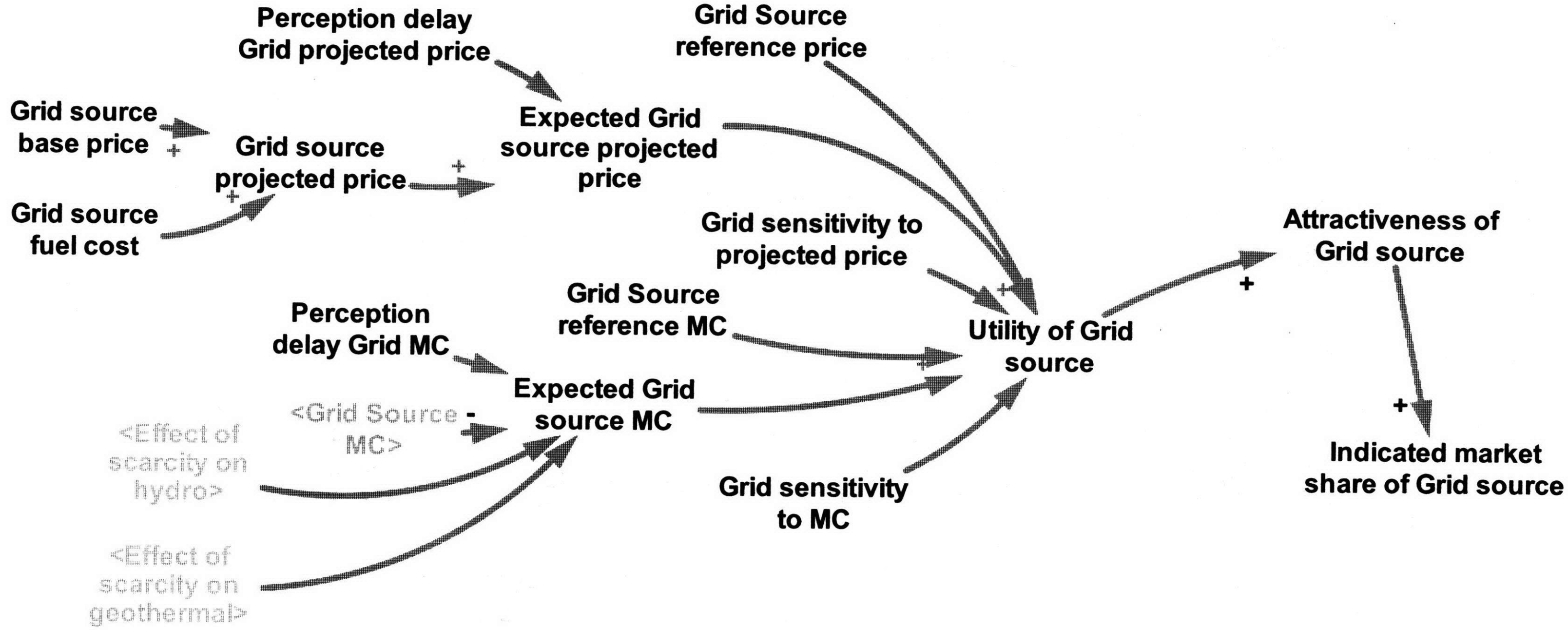
FinTech Model - Resource depletion cost



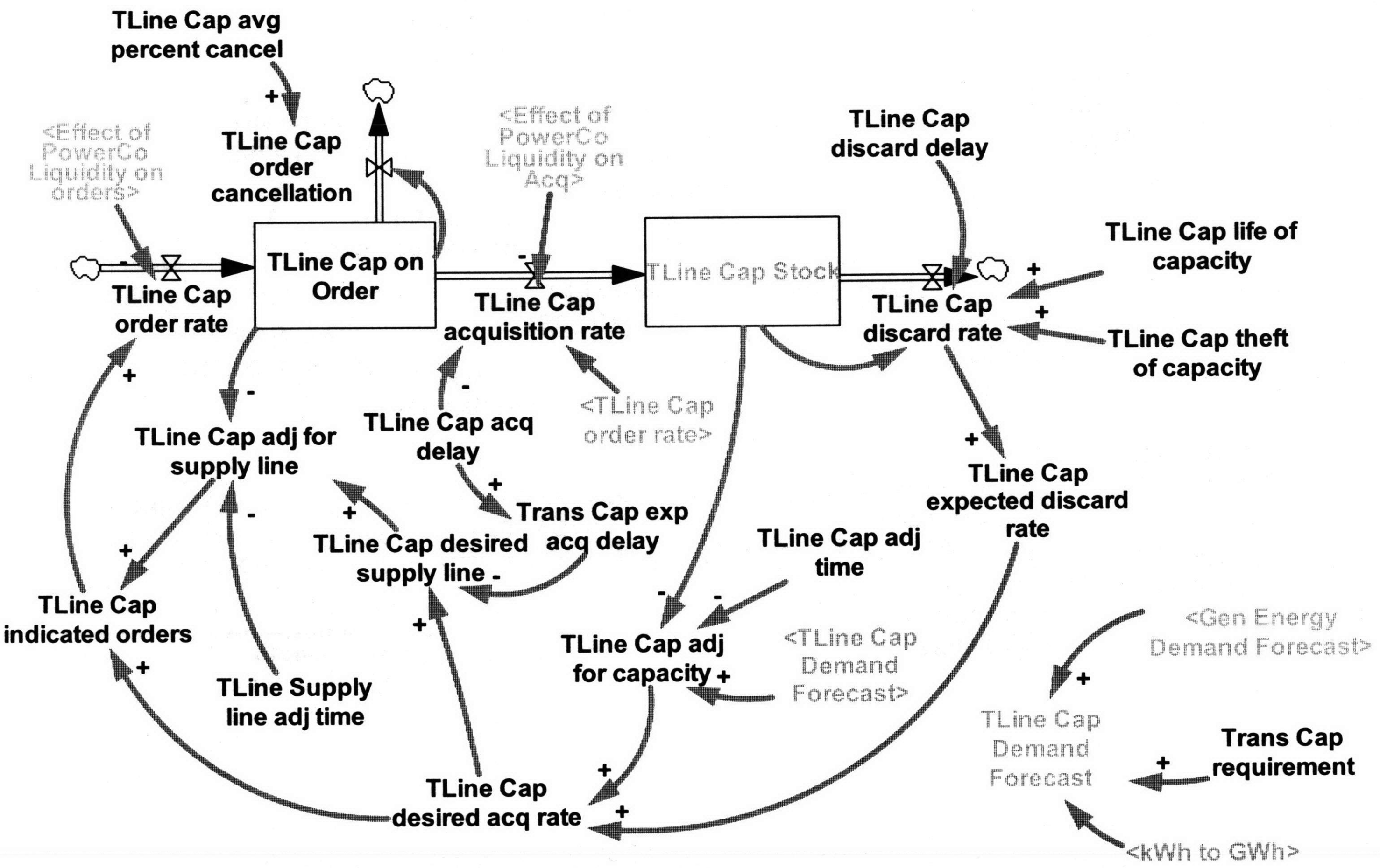
Technical Model - Generation capacity



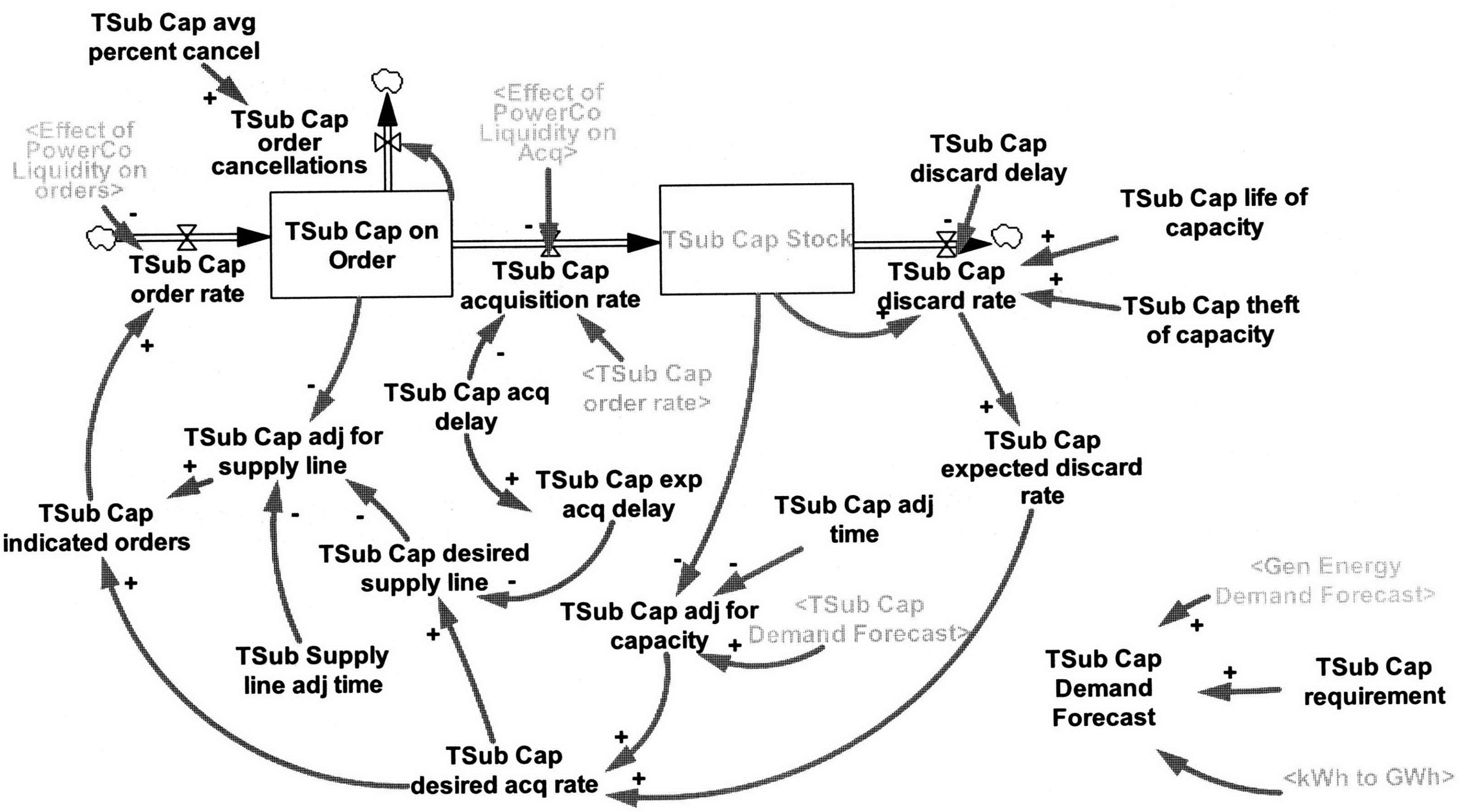
Technical Model - Generation capacity planning



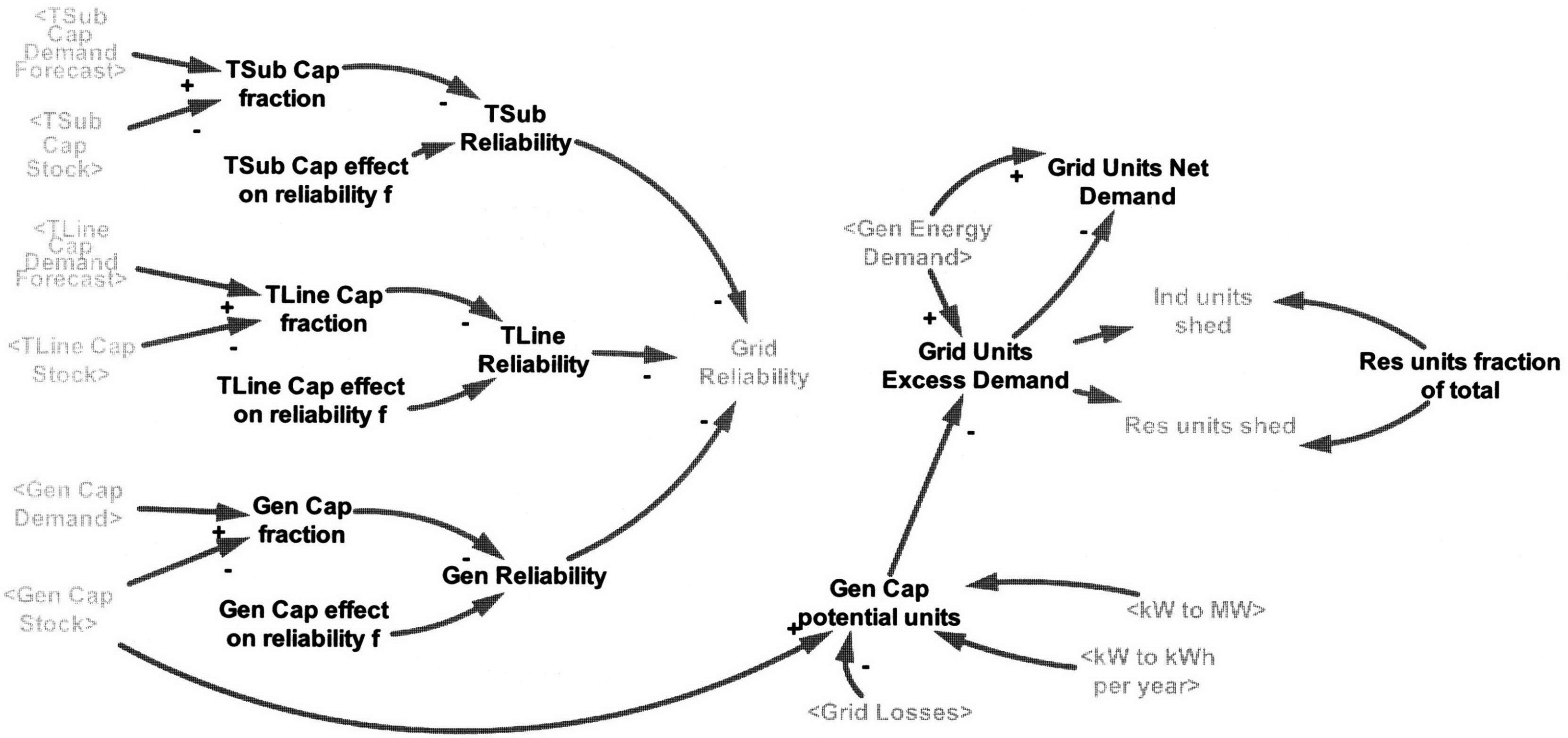
Technical Model - Transmission line capacity



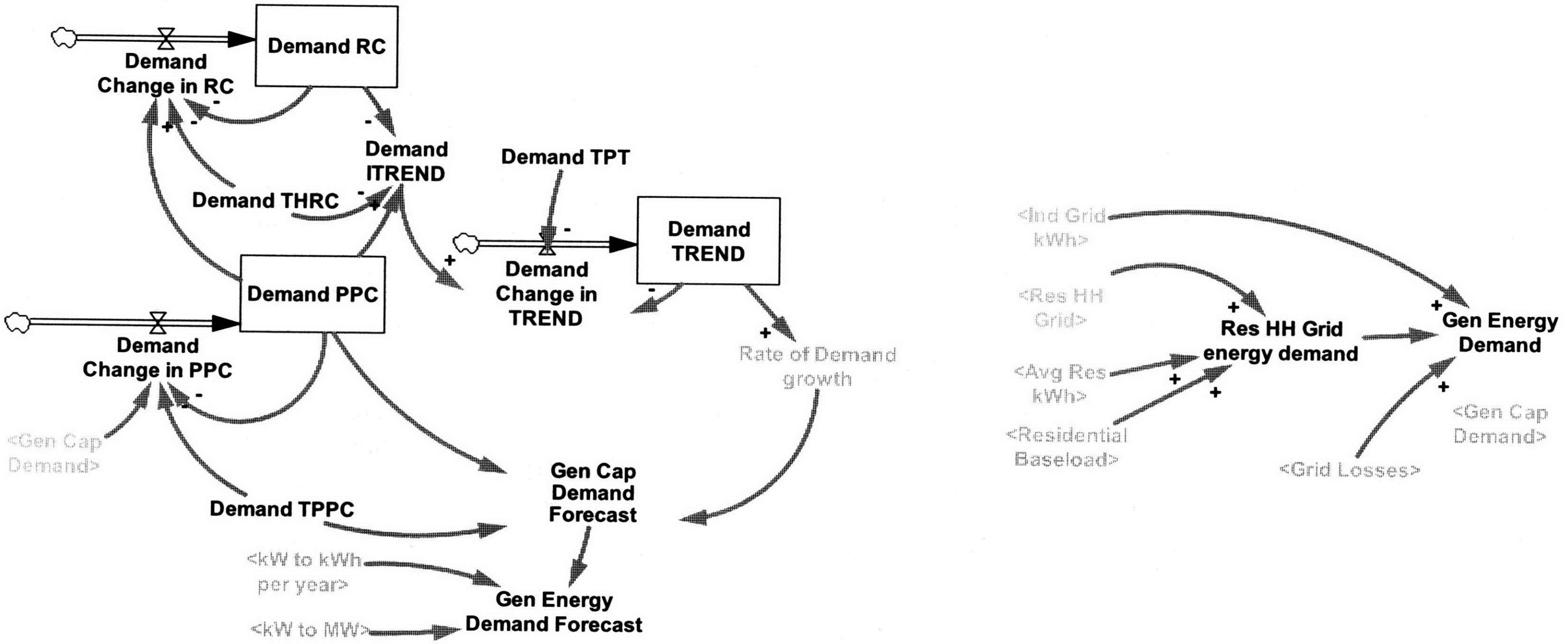
Technical Model - Transmission substation capacity



Technical Model - Reliability



Technical Model - Demand forecast



Model variables

Variable	Equation	Units	Comment	Type
Attractiveness Ind Options[Industrial options]	EXP(Utility Ind Options[Industrial options])	dmnl	Attractiveness of the industrial options.	AUXILIARY
Attractiveness of Grid source[Grid sources]	EXP(Utility of Grid source[Grid sources])	dmnl	The attractiveness of the different grid sources represents the relative \ attractiveness to the power company in planning capacity additions. The \ attractiveness is based solely on the marginal cost of adding capacity of \ the different options.	AUXILIARY
Attractiveness Res Options[Population , Residential options]	EXP(Utility Res Options[Population, Residential options])	dmnl	Attractiveness of the different options for both urban and rural customers.	AUXILIARY
Default or bailout	PowerCo Debt*Percent of debt bailout	KSh/Year [0,1e+012]	Flow out of estimated debt repayment based on government bailout, \ international aid, or default on loan. Assumes a portion of the debt goes \ away without repayment.	AUXILIARY
Demand Change in PPC	(Gen Cap Demand-Demand PPC)/Demand TPPC	MW/Year	Change in perceived present condition. Source: Sterman, J. 2000. Business \ Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: \ Irwin-McGraw Hill.	AUXILIARY
Demand Change in RC	(Demand PPC-Demand RC)/Demand THRC	MW/Year	Change in reference condition. Source: Sterman, J. 2000. Business \ Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: \ Irwin-McGraw Hill.	AUXILIARY
Demand Change in TREND	(Demand ITREND-Demand TREND)/Demand TPT	1/Year/Year	Change in trend, over the time to perceive the trend. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Demand ITREND	((Demand PPC-Demand	1/Year	Estimated trend for demand growth. Source:	AUXILIARY

	RC)/Demand RC)/Demand THRC		Sterman, J. 2000. Business \ Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: \ Irwin-McGraw Hill.	
Desired Connect from Diesel[Population]	Res HH OffGrid Diesel[Population]*Percent desired connect Diesel	Households/ Year [0,1e+006]	Annual number of households who are using a diesel generator that would \ choose to be connected to the grid.	AUXILIARY
Desired Connect from Renew[Population]	Percent desired connect Renew*Res HH OffGrid Renew[Population]	Households/ Year	Annual number of households who are using a PV system that would choose to \ be connected to the grid.	AUXILIARY
Desired Grid Connect from NoElec[Population]	Res HH PotentialAdopters[Population]*Indicated share Res Options[Population, ResGrid\ ]	Households/ Year	Estimated number of households who currently have no electricity that will \ want a grid connection in a given year, based on the indicated market \ share.	AUXILIARY
Diesel price Kenya	World oil to Kenya oil*Projected oil price/Density of diesel	KSh/kg	Calculates the price of diesel in kg in Kenya from the projected world oil \ price.	AUXILIARY
Effect of Desired Percent Urban on Urbanization	Urban capacity effect f(Percent Urban/Desired Percent Urban)	dmnl	This is the effect of the capacity of the cities on the rate of \ urbanization. It assumes that urbanization will slow as the carrying \ capacity of the city is reached.	AUXILIARY
Effect of PowerCo Liquidity on Acq	SMOOTH((Effect of PowerCo Liquidity on Acq f(PowerCo Liquidity)), PowerCo Time to perceive cash flow\ )	dmnl	Generates a factor to reduce capacity acquisition based on lack of cash \ flow.	AUXILIARY
Effect of PowerCo Liquidity on orders	SMOOTH((Effect of PowerCo Liquidity on Orders f(PowerCo Liquidity)), PowerCo Time to perceive cash flow\ )	dmnl	Generates a factor to reduce capacity acquisition based on lack of cash \ flow.	AUXILIARY
Effect of scarcity on geothermal	Scarcity cost of geotherm f(Geothermal percent potential remaining)	dmnl	Increase in cost due to diminishing geothermal resource. Geothermal \ resources will be more expensive as the least cost sites are developed \ first.	AUXILIARY
Effect of scarcity on hydro	Scarcity cost of hydro f(Hydropower percent potential remaining)	dmnl	Additional cost factor based on the declining availability of inexpensive \ sources of hydropower.	AUXILIARY
Exp Ind Capex[Industrial	SMOOTH(Ind Capex[Industrial options], Perception delay Ind	KSh/system	This function smooths the transition in price so it is perceived over time \ instead of instantly upon	AUXILIARY

options]	Capex)		changing.	
Exp Ind Reliability[Industrial options]	SMOOTH(Ind Reliability[Industrial options], Perception delay Ind Reliability)	dmnl	This function smooths the transition in price so it is perceived over time \ instead of instantly upon changing.	AUXILIARY
Exp Ind Unit price[Industrial options]	SMOOTH(Ind Unit price[Industrial options], Perception delay Ind Unit price)	KSh/(kilowatt *hour)	This function smooths the transition in price so it is perceived over time \ instead of instantly upon changing.	AUXILIARY
Exp Res Backlog[Population, Residential options]	SMOOTH(Res Perceived backlog[Population,Residential options], Perception delay Res Backlog\ )	dmnl	This function smooths the transition in perceived backlog so it is \ perceived over time instead of instantly upon changing.	AUXILIARY
Exp Res Capex[Population, Residential options]	SMOOTH(Res Capex[Population, Residential options], Perception delay Res Capex)	KSh/household	This function smooths the transition in price so it is perceived over time \ instead of instantly upon changing.	AUXILIARY
Exp Res Reliability[Population, Residential options]	SMOOTH(Res Reliability[Population, Residential options], Perception delay Res Reliability\ )	dmnl	This function smooths the transition in reliability so it is perceived \ over time instead of instantly upon changing.	AUXILIARY
Exp Res Unit price[Population, Residential options]	SMOOTH(Res Unit price[Population, Residential options], Perception delay Res Unit price\ )	KSh/(kilowatt *hour)	This function smooths the transition in price so it is perceived over time \ instead of instantly upon changing.	AUXILIARY
Expected Grid source MC[Thermal]	SMOOTH(Grid Source MC[Thermal], Perception delay Grid MC)			AUXILIARY
Expected Grid source projected price[Grid sources]	SMOOTH(Grid source projected price[Grid sources], Perception delay Grid projected price\ )	KSh/(kilowatt *hour)	This function smooths the transition in price so it is perceived over time \ instead of instantly upon changing.	AUXILIARY
Fraction Connect Diesel[Population]	Desired Connect from Diesel[Population]/Res HH Desired Grid Connect[Population]	dmnl	Allocates the fraction of new connections which will come from diesel \ off-grid users.	AUXILIARY
Fraction Connect NoElec[Population]	Desired Grid Connect from NoElec[Population]/Res HH Desired Grid Connect[Population]	dmnl	Allocates the fraction of new connections which will come from diesel \ off-grid users.	AUXILIARY
Fraction Connect Renew[Population]	Desired Connect from Renew[Population]/Res HH Desired	dmnl	Allocate what fraction of grid connections will go to renewable off-grid \ users.	AUXILIARY

	Grid Connect[Population]			
Gen Cap acquisition rate[Grid sources]	DELAY3(Gen Cap order rate[Grid sources]*Effect of PowerCo Liquidity on Acq, Gen Cap acq delay\ [Grid sources])	MW/Year	This is the rate of building new capital once it is on order. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap adj for capacity[Grid sources]	(Gen Cap Demand Forecast-Gen Cap Stock[Grid sources])/Gen Cap adj time	MW/Year	This is the needed capacity to meet the new demand. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap adj for supply line[Grid sources]	(Gen Cap desired supply line[Grid sources]-Gen Cap on Order[Grid sources])/Gen Supply line adj time	MW/Year	This is the new capacity required in order to meet the supply line \ requirments. It takes into account capacity already on order. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap Demand	(kW to MW*((Ind Grid kWh/kW to kWh per year)+(Sum(Res HH Grid[Population!])*Avg Res Cap\ [ResOGRenew]))+(Residential Baseload /kW to kWh per year*kW to MW))*(1+Gen Cap desired margin)	MW	This converts then energy demand from industry and households to the \ required capacity to meet that demand.	AUXILIARY
Gen Cap Demand Forecast	Demand PPC*(1+Rate of Demand growth*Demand TPPC)	MW	Estimated generation capacity needed, forecasted based on the perceived \ demand from customers.	AUXILIARY
Gen Cap desired acq rate[Grid sources]	Gen Cap adj for capacity[Grid sources]+Gen Cap expected discard rate[Grid sources]	MW/Year	This the desired rate of new capital acquisitions based on the demand and \ rate of discard of existing capacity. Source: Sterman, J. 2000. Business \ Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: \ Irwin-McGraw Hill.	AUXILIARY
Gen Cap desired supply line[Grid sources]	Gen Cap exp acq delay[Grid sources]*Gen Cap desired acq rate[Grid sources]	MW	This is the desired supply line of new capacity. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap discard rate[Grid sources]	(DELAY3I(Gen Cap Stock[Grid sources]/Gen Cap life of capacity[Grid sources] , Capacity	MW/Year	This is the discard rate for capacity, which is based on the expected life \ of capacity.	AUXILIARY

	discard delay\ , Gen Cap Stock[Grid sources]/Gen Cap life of capacity[Grid sources]))			
Gen Cap exp acq delay[Grid sources]	Gen Cap acq delay[Grid sources]	Years	This is the expected delay in building new capacity, based on the \ estimated delay. Source: Sterman, J. 2000. Business Dynamics: Systems \ Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap expected discard rate[Grid sources]	Gen Cap discard rate[Grid sources]	MW/Year	This is the expected Discard rate, based on the real discard rate. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap fraction	Gen Cap Demand/Sum(Gen Cap Stock[Grid sources!])	dmnl	This is the fraction of total demand compared to capacity available. If \ it is less than 1 that means there is sufficient capacity available, if it \ is over 1 then there is a shortfall.	AUXILIARY
Gen Cap indicated orders[Grid sources]	Gen Cap desired acq rate[Grid sources]+Gen Cap adj for supply line[Grid sources]	MW/Year	This is the indicated order rate for new capacity. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap order cancellations[Grid sources]	Gen Cap on Order[Grid sources]*Gen Cap avg percent cancel	MW/Year	New capacity on order that is cancelled each year. Cancellations come \ from a range of undesignated sources, such as changes in planning, or from \ the effect of the poor liquidity of the power company.	AUXILIARY
Gen Cap order rate[Grid sources]	MAX(0, (Gen Cap indicated orders[Grid sources]*Indicated market share of Grid source\ [Grid sources]*Effect of PowerCo Liquidity on orders))	MW/Year	This is the rate of ordering new capacity. Source: Sterman, J. 2000. \ Business Dynamics: Systems Thinking and Modeling for a Complex World. \ Chicago: Irwin-McGraw Hill.	AUXILIARY
Gen Cap potential units	(1-Grid Losses)*Sum(Gen Cap Stock[Grid sources!])/kW to MW*kW to kWh per year	(kilowatt*hour)/Year	Potential number of kWh generated by the current capital stock. Is used \ to compare to the number of units consumers are demanding.	AUXILIARY
Gen Energy Demand	SIMULTANEOUS ((Res HH Grid energy demand+Ind Grid kWh)*(1+(1-Grid Losses)),	(kilowatt*hour)/Year	Total grid energy demanded by both the residential and industrial \ consumers.	AUXILIARY

	3e+009)			
Gen Energy Demand Forecast	Gen Cap Demand Forecast*kW to kWh per year/kW to MW	(kilowatt*hour)/Year	Demand for Energy based on predicted trend for capacity demand. Estimated \ energy capacity is the number of kWh per year potential for the forecasted \ generation capacity required.	AUXILIARY
Gen Prob failure	Gen Cap effect on failure f(Gen Cap fraction)	dmnl	Estimation of the probability of failure due to the relative generation \ capacity.	AUXILIARY
Geotherm Cap additions	MAX(0, Gen Cap acquisition rate[Geotherm])	MW/Year	Added geothermal capacity subtracts from the total potential still \ available.	AUXILIARY
Geothermal percent potential remaining	Geothermal potential/Geothermal initial potential	dmnl	Percent of available geothermal potential that can still be exploited.	AUXILIARY
Grid Capacity MC[Grid sources]	Grid OM Capacity MC[Grid sources]*Grid Percent Source[Grid sources]	$/(kilowatt*Year)	Marginal cost of grid capacity overall, based on generation source mix.	AUXILIARY
Grid Connections from Diesel[Population]	MIN(Max Connect from Diesel[Population], Desired Connect from Diesel[Population])	Households/ Year	Number of grid connections each year from off-grid diesel users.	AUXILIARY
Grid Connections from Renew[Population]	(MIN(Max Connect from Renew[Population], Desired Connect from Renew[Population]))	Households/ Year	Number of connections from renewable off-grid users to the grid. Since \ the desired connections are assumed to be zero, there are no connections.	AUXILIARY
Grid Connections[Population]	(MIN(Max Connect from NoElec[Population], Desired Grid Connect from NoElec[Population\ ]))	Households/ Year	Number of grid connections per year based on the indicated market share \ and the ability of the power company to meet demand.	AUXILIARY
Grid Customer MC	Grid Forex charge+Grid Fuel charge	KSh/(kilowatt*hour)	This is the added marginal cost per unit passed to the customer from the \ fees for foreign exchange and fuel charges.	AUXILIARY
Grid Energy MC[Grid sources]	Grid Energy Unit MC[Grid sources]*Grid Percent Source[Grid sources]	$/(kilowatt*hour)	Calculates marginal cost for energy costs per unit based on the capacity \ mix.	AUXILIARY
Grid ERB Ind Price	ACTIVE INITIAL (DELAY1(Grid Indicated Ind Price, ERB Delay in price regulation)+Grid Forex charge+Grid Fuel charge\ , Grid Ind Base unit price initial+Grid Forex charge+Grid Fuel charge)	KSh/(kilowatt*hour)	ERB set price for industrial consumers in the B2 category.	AUXILIARY

Grid ERB Res Price	ACTIVE INITIAL (DELAY1(Grid Indicated Res Price, ERB Delay in price regulation)+Grid Forex charge+Grid Fuel charge\ , Grid Res Base unit price initial+Grid Forex charge+Grid Fuel charge)	KSh/(kilowatt *hour)	Price regulated by the ERB for residential consumption between 51-300 \ kWh/month	AUXILIARY
Grid Forex charge	MAX(0, (1/1-Grid Losses)*(((Percent change in exchange rate*Sum of forex costs)+Sum of forex costs\ )/Gen Energy Demand))	KSh/(kilowatt *hour)	Additional customer charge for foreign exchange correction. Source: Kenya \ Power & Lighting Company, Schedule of Rates, Part III Other Charges. \ Online: http://www.kplc.co.ke.	AUXILIARY
Grid Fuel charge	((1/(1-Grid Losses))*(((Diesel price Kenya*Avg Grid Ind Specific fuel consumption*Grid Thermal units\ )/Gen Energy Demand)-Base fuel cost Kenya))	KSh/(kilowatt *hour)	Additional charge to account for changes in fuel cost. Source: Kenya \ Power & Lighting Company, Schedule of Rates, Part III Other Charges. \ Online: http://www.kplc.co.ke.	AUXILIARY
Grid Indicated Ind Price	Grid Indicated Price*(1/Grid Ratio Res to Ind)	KSh/(kilowatt *hour)	Indicated price for grid industrial consumers.	AUXILIARY
Grid Indicated Price	((Grid Customer MC+(Sum(Grid Capacity MC[Grid sources!])*Real exchange rate/kW to kWh per year\ )+(Sum(Grid Energy MC[Grid sources!])*Real exchange rate))*(1+Grid VAT))+Grid ERB Levy	KSh/(kilowatt *hour)	Calculated price for grid electricity. Source: Kenya Power & Lighting \ Company, Schedule of Rates, Part III Other Charges. Online: \ http://www.kplc.co.ke.	AUXILIARY
Grid Indicated Res Price	Grid Indicated Price*Grid Ratio Res to Ind	KSh/(kilowatt *hour)	Indicated price for grid residential consumers.	AUXILIARY
Grid Percent Source[Grid sources]	Gen Cap Stock[Grid sources]/Sum(Gen Cap Stock[Grid sources!])	dmnl	Percent of power generated for the grid by each source.	AUXILIARY
Grid Reliability	(1-Gen Prob failure)*(1-TLine Prob failure)*(1-TSub Prob failure)	dmnl	Probability of no failure on the system, based on the probability of \ failures in the generation and transmission system.	AUXILIARY
Grid source fuel cost[Thermal]	Grid Fuel charge			AUXILIARY

Grid source projected price[Grid sources]	(Grid source base price[Grid sources]*Real exchange rate)+Grid source fuel cost[Grid sources\ ]	KSh/(kilowatt *hour)	Projected price per unit of future capacity used in determining best \ capacity expansion plans.	AUXILIARY
Grid Thermal units	Gen Energy Demand*Grid Percent Source[Thermal]	(kilowatt*hour)/Year	Number of grid units generated from thermal sources, which are used to \ calculate the fuel surcharge.	AUXILIARY
Grid Units Excess Demand	SIMULTANEOUS (MAX(0, Gen Energy Demand-Gen Cap potential units), 0)	(kilowatt*hour)/Year	Number of kWh demanded that are above what the current capacity can \ supply. This is the amount that must be eliminated through load shedding.	AUXILIARY
HH Growth[Rural]	(Rur PopGrowth)/Avg household			AUXILIARY
Hydro Cap additions	MAX(0, (Gen Cap acquisition rate[Hydro])+((Switch Grid to OffGrid[IndOGHydro]+Ind OffGrid Growth\ [IndOGHydro]+Switch in OffGrid to OffGrid[IndOGHydro])*kW to MW/kW to kWh per year)\ )	MW/Year	As hydropower capacity is added to the grid system it is subtracted from \ the available hydropower capacity.	AUXILIARY
Hydropower percent potential remaining	Hydropower potential/Hydropower initial potential	dmnl	Percent of available hydropower potential that can still be exploited.	AUXILIARY
Ind Capex[IndOGDiesel]	Ind Diesel system*Real exchange rate			AUXILIARY
Ind Diesel fuel	Diesel price Kenya*Avg Grid Ind Specific fuel consumption	KSh/(kilowatt *hour)	Fuel cost per kWh for industrial off-grid diesel users, based on local \ diesel prices and industrial scale fuel consumption.	AUXILIARY
Ind Diesel system	Ind Diesel capex*Avg Ind Cap	$/system	Cost of diesel generator based on expected average capacity.	AUXILIARY
Ind Diesel unit price	(Ind Diesel OandM*Real exchange rate)+Ind Diesel fuel	KSh/(kilowatt *hour)	The unit price of industrial off-grid diesel systems is based on the \ operations and maintenace cost of diesel, plus the cost of fuel.	AUXILIARY
Ind Grid Growth[IndGrid]	Ind kWh Total*Indicated share Ind Options[IndGrid]*Industrial Growth	(kilowatt*hour)/Year/Year	Added grid units per year based on the estimated growth rate and the \ indicated market share for grid.	AUXILIARY
Ind Grid Units shifting	Ind Grid kWh*Ind Percent Potential shift	(kilowatt*hour	Number of grid units potentially being reallocated each year.	AUXILIARY

		)/Year/Year		
Ind Hydro system	Ind Hydro cost*Avg Ind Cap*Effect of scarcity on hydro	$/system	Cost of an industrial hydropower system based on the cost per kW \ installed, the average industrial capacity, and the increase in hydropower \ cost due to scarcity.	AUXILIARY
Ind kWh Total	Ind Grid kWh+Ind OffGrid kWh[IndOGDiesel]+Ind OffGrid kWh[IndOGHydro]+Ind OffGrid kWh\ [IndOGRenew]	(kilowatt*hour)/Year	Total electricity "sales" to grid and off-grid industrial consumers in a \ year.	AUXILIARY
Ind OffGrid Growth[IndOGDiesel]	Ind kWh Total*Indicated share Ind Options[IndOGDiesel]*Industrial Growth			AUXILIARY
Ind OffGrid Units shifting[IndOGDiesel]	Ind OffGrid kWh[IndOGDiesel]*Ind Percent Potential shift			AUXILIARY
Ind Reliability[IndGrid]	Grid Reliability			AUXILIARY
Ind Unit price[IndOGRenew]	Ind Renew unit price*Real exchange rate			AUXILIARY
Ind units shed	Grid Units Excess Demand*Bias for shedding Res load	(kilowatt*hour)/Year	Units per year that are "shed" from the units that would be sold to \ industrial consumers.	AUXILIARY
Indicated market share of Grid source[Grid sources]	Attractiveness of Grid source[Grid sources]/Sum(Attractiveness of Grid source[Grid sources\ !])	dmnl	The indicated market share of each grid source estimates the percent of \ new capacity that should come from each potential grid source, based on \ the marginal cost of capacity to the power company.	AUXILIARY
Indicated share Ind Options[Industrial options]	Attractiveness Ind Options[Industrial options]/Sum(Attractiveness Ind Options[Industrial options\ !])	dmnl	This variable represents the indicated market share of each of the options \ for industrial consumers. Under ideal circumstances, this is the fraction \ of consumers that would be in each of the categories of type of \ electricity connection.	AUXILIARY
Indicated share Res Options[Population , Residential	Attractiveness Res Options[Population, Residential options]/Sum(Attractiveness Res Options\ [Population, Residential	dmnl	This variable represents the indicated market share of each of the options \ for residential consumers, both urban and rural. Under ideal \ circumstances, this is the fraction of consumers	AUXILIARY

options]	options!])		that would be in each of \ the categories of type of electricity connection.	
Interest on Debt	Interest rate*PowerCo Debt	KSh/Year	Yearly interest payments on debt, in addition to payback on principal \ (variable PowerCo Repayment).	AUXILIARY
Interest rate	IF THEN ELSE(PowerCo Debt>0, Interest rate on debt, Interest rate on cash)	dmnl/Year	Distinguishes between interest rate on debt versus interest rate on cash, \ depending on whether cash flow is positive or negative.	AUXILIARY
Max Connect from Diesel[Population]	PowerCo Connect capacity[Population]*Fraction Connect Diesel[Population]	Households/ Year	Maximum connections in a year of diesel off-grid users.	AUXILIARY
Max Connect from NoElec[Population]	Fraction Connect NoElec[Population]*PowerCo Connect capacity[Population]	Households/ Year	Maximum number of connections per year from households that have no \ electricity.	AUXILIARY
Max Connect from Renew[Population]	PowerCo Connect capacity[Population]*Fraction Connect Renew[Population]	Households/ Year	Maximum connections of renewable households the power company is able to \ do in a year.	AUXILIARY
OffGrid Diesel Sales[Population]	(Res HH PotentialAdopters[Population]*Indicated share Res Options[Population, ResOGDiesel\ ])	Households/ Year	Number of potential adopter households that will buy diesel generator \ systems in a year, based on the indicated market share.	AUXILIARY
OffGrid Renew Sales[Population]	(Res HH PotentialAdopters[Population]*Indicated share Res Options[Population, ResOGRenew\ ])	Households/ Year	Number of potential adopter households per year that will buy PV systems \ based on the indicated market share.	AUXILIARY
Percent change in exchange rate	((Real exchange rate-Base exchange rate)/Base exchange rate)*100	dmnl	From overall equation this is variable (Z), percent change in exchange \ rate from base of 65 KSh	AUXILIARY
Percent Urban	Urb Population/Total Population	dmnl	Percent of the total population that lives in urban areas.	AUXILIARY
PowerCo Cash flow	(PowerCo Revenue Total-(PowerCo Expense Cap maintenance +PowerCo Repayment+Interest on Debt+PowerCo Payroll)-(PowerCo Revenue Total*(PowerCo Taxes\	KSh/Year	The power company cash flow is the revenue from sales, minus the expenses \ for taxes and maintenance of assets.	AUXILIARY

	+PowerCo Expense Grid REP Levy+PowerCo Corruption tax)))			
PowerCo Connect capacity[Population]	PowerCo Connect target[Population]*PowerCo Connect success percent	Households/ Year	This is the real number of households per year that the power company is \ able to connect.	AUXILIARY
PowerCo Cost of new construction	((Sum(Expected Grid source MC[Grid sources!])*Sum(Gen Cap acquisition rate[Grid sources\ !])/kW to MW)+(TLine Cap acquisition rate *TLine construction cost)+(TSub Cap acquisition rate*TSub construction cost))*Real exchange rate	KSh/Year [0,1]	Resources need to cover cost of new construction. Compared to cash flow \ to determine if power company can add capacity.	AUXILIARY
PowerCo Expense Cap maintenance	(Gen Energy Demand*Price paid for generation)+(TSub Cap cost of maintenance*TSub Cap Stock\ *Real exchange rate)+(TLine Cap cost of maintenance *TLine Cap Stock*Real exchange rate)	KSh/Year	This is the total cost of maintaining the existing assets of the power \ company. These are expenses that are covered by the revenue generated by \ the power company. The higher the expenses relative to revenue, the lower \ the cash flow available for investment in new capacity.	AUXILIARY
PowerCo Liquidity	ACTIVE INITIAL (MAX(0, PowerCo Cash flow)/PowerCo Cost of new construction, 0.1)	dmnl	Comparison of cash flow to cash required to cover operations. Used to \ determine if there is sufficient funds to expand capacity. Initialized \ with the assumption that there is insufficient cash flow to meet demands \ of construction. Initialized in part to avoid simultaneous equation error.	AUXILIARY
PowerCo Performance	PowerCo Percent Bills collected*PowerCo Percent Meters read	dmnl	This is a measure of the performance of the power company in terms of \ revenue collected from the total possible amount.	AUXILIARY
PowerCo Repayment	PowerCo Debt/PowerCo Debt Maturity	KSh/Year	Repayment of power company debt over estimated loan repayment period.	AUXILIARY
PowerCo Rev from Ind	Grid Indicated Ind Price*(Ind Grid kWh-Ind units shed)*PowerCo Performance	KSh/Year	This is the revenue generated from industrial grid power customers. It is \ calculated from the total grid units consumed by industrial users, \ multiplied by the indicated price and the performance of the power company \ at revenue collection, minus the units shed due to unmet	AUXILIARY

			demand.	
PowerCo Rev from Res	((Sum(Res HH Grid[Population!])*Avg Res kWh)-Res units shed+Residential Baseload)*Grid Indicated Res Price\ *PowerCo Performance	KSh/Year	This is the revenue generated from residential household customers of the \ power company. It is the number of households (both urban and rural), \ multiplied by the average use, adding the baseload customers, subtracting \ the units shed due to excess demand, and multiplying by the indicated \ price per unit and the performance of the power company at revenue \ collection.	AUXILIARY
PowerCo Revenue Total	PowerCo Rev from Ind+PowerCo Rev from Res	KSh/Year	This is the total revenue to the power company from both residential and \ industrial sources.	AUXILIARY
PowerCo Shortfall	MAX(0, -PowerCo Cash flow)	KSh/Year	If the cash flow to the power company is negative, the gap is assumed to \ be filled by external loans.	AUXILIARY
Rate of Demand growth	Demand TREND	1/Year	Growth in demand as estimated by the TREND structure. It is used to \ estimate the growth in demand based on recent data. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
Res Capex[Population, ResOGDiesel]	Res Diesel system*Real exchange rate			AUXILIARY
Res Diesel fuel	Avg Res Specific Fuel Consumption*Diesel price Kenya	KSh/(kilowatt *hour)	Fuel cost for residential diesel generator users.	AUXILIARY
Res Diesel system	Avg Res Cap[ResOGDiesel]*Res Diesel capex	$/household	Cost of a diesel system to a residential consumers, based on average size \ of generator.	AUXILIARY
Res Diesel unit price	(Res Diesel OandM*Real exchange rate)+Res Diesel fuel	KSh/(kilowatt *hour)	Price per kWh for off-grid diesel, based on the operations and maintenance \ cost plus the fuel costs.	AUXILIARY
Res HH Desired Grid Connect[Population]	Desired Connect from Diesel[Population]+Desired Connect from Renew[Population]+Desired Grid Connect from NoElec\ [Population]	Households/ Year	Total number of households wanting a grid connection in a year.	AUXILIARY
Res HH Grid Backlog	MAX(1, Res HH Desired Grid Connect[Population]/PowerCo	dmnl	Ratio of desired grid connections to capacity to connect. As long as \ variable is greater than one,	AUXILIARY

Ratio[Population]	Connect capacity[Population])		there is a backlog. If the variable is less \ than one it means the power company has sufficient resources to meet \ customer demand.	
Res HH Grid energy demand	(Sum(Res HH Grid[Population!])*Avg Res kWh)+Residential Baseload-Res units shed	(kilowatt*hour)/Year	Total residential grid energy demand, based on the number of households \ connected to the grid and their average demand. An additional baseload \ demand is added to account for the initial high consuming customers, see \ explanation in variable description.	AUXILIARY
Res HH NoPower AffordElec[Population]	Res HH NoElec[Population]*(1-Projected Percent Population in poverty[Population])	Households	Number of households living above the stated poverty line in Kenya. \ Households who are below the poverty line are assumed to not be able to \ afford electricity so are not potential adoptors.	AUXILIARY
Res HH PotentialAdopters[Population]	Res ContactRate[Population]*Res AdoptionFraction[Population]*Res HH NoPower AffordElec\ [Population]*Res HH TotalElec[Population]/Total HH	Households/ Year	Word of mouth spread of electricity interest. Source: Sterman, J. 2000. \ Business Dynamics: Systems Thinking and Modeling for a Complex World. \ Chicago: Irwin-McGraw Hill. Bass diffusion model pg. 332-334.	AUXILIARY
Res HH TotalElec[Population]	Res HH OffGrid Diesel[Population]+Res HH OffGrid Renew[Population]+Res HH Grid[Population\ ]	Households	Total number of households with some form of electricity.	AUXILIARY
Res Perceived backlog[Urban, ResGrid]	ACTIVE INITIAL (Res HH Grid Backlog Ratio[Urban], 1)			AUXILIARY
Res Reliability[Population,ResGrid]	Grid Reliability			AUXILIARY
Res Renew system	((Projected PV price+Kenya PV surcharge)/W to kW*Avg Res Cap[ResOGRenew])+Res PV Components cost	$/household	Cost of a renewable system to a residential consumers, based on price of \ PV and Kenya surcharges and calibrated using real prices from Kenya \ dealers.	AUXILIARY
Res Unit price[Population,ResGrid]	Grid Indicated Res Price			AUXILIARY
Res units shed	Grid Units Excess Demand*(1-Bias for shedding Res load)	(kilowatt*hour	Units per year that are "shed" from the units that would be sold to \ residential consumers.	AUXILIARY

		)/Year		
Rur Grid initial	Rur population initial*Rur Percent Grid initial	People	People in rural areas with access to electricity in 1995.	AUXILIARY
Rur PopGrowth	Rur Percent Growth*Rur Population	People/Year	Population growth based on fixed percent growth.	AUXILIARY
Rur population initial	Population initial*Rur Percent Pop initial	People	People living in rural areas in Kenya in 1995.	AUXILIARY
Switch Grid to OffGrid[IndOGDiesel]	(Ind Grid Units shifting*Indicated share Ind Options[IndOGDiesel])			AUXILIARY
Switch in OffGrid to OffGrid[IndOGDiesel]	((Ind OffGrid Units shifting[IndOGHydro]+Ind OffGrid Units shifting[IndOGRenew])*Indicated share Ind Options\ [IndOGDiesel])			AUXILIARY
Switch OffGrid to Grid[IndOGDiesel]	(Ind OffGrid Units shifting[IndOGDiesel]*Indicated share Ind Options[IndGrid])			AUXILIARY
TLine Cap acquisition rate	DELAY3(TLine Cap order rate*Effect of PowerCo Liquidity on Acq, TLine Cap acq delay)	Miles/Year	The supply chain for capacity assumes a third-order capacity acquisition \ delay. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking and \ Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TLine Cap adj for capacity	(TLine Cap Demand Forecast-TLine Cap Stock)/TLine Cap adj time	Miles/Year	This is the adjustment in capacity demand based on the gap between desired \ stock and actual capacity. Source: Sterman, J. 2000. Business Dynamics: \ Systems Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw \ Hill.	AUXILIARY
TLine Cap adj for supply line	(TLine Cap desired supply line-TLine Cap on Order)/TLine Supply line adj time	Miles/Year	This is the capacity orders needed to fill the gap between desired \ capacity in supply line and actual capacity in the supply line. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TLine Cap Demand Forecast	Gen Energy Demand Forecast*Trans Cap	Miles	Estimation of the number of miles of transmission line needed to carry the \ annual energy load of	AUXILIARY

	requirement*kWh to GWh		the system.	
TLine Cap desired acq rate	TLine Cap expected discard rate+TLine Cap adj for capacity	Miles/Year	This is the replacement of espected iscards, adjusted in response to the \ gap between desired and actual capital stocks. Source: Sterman, J. 2000. \ Business Dynamics: Systems Thinking and Modeling for a Complex World. \ Chicago: Irwin-McGraw Hill.	AUXILIARY
TLine Cap desired supply line	Trans Cap exp acq delay*TLine Cap desired acq rate	Miles	The amount of capacity the producer must have on order and under \ construction to yield the desired acquisition rate. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TLine Cap discard rate	DELAY3I((TLine Cap Stock/TLine Cap life of capacity)+TLine Cap theft of capacity , \ TLine Cap discard delay , TLine Cap Stock /TLine Cap life of capacity)	Miles/Year	This is the estimated total loss in capacity per year due to both decay of \ lines and theft of lines. Source: Sterman, J. 2000. Business Dynamics: \ Systems Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw \ Hill.	AUXILIARY
TLine Cap expected discard rate	TLine Cap discard rate	Miles/Year	This is the expected discard rate, based on the estimation of losses due \ to theft and retirment of equipment. Source: Sterman, J. 2000. Business \ Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: \ Irwin-McGraw Hill.	AUXILIARY
TLine Cap fraction	TLine Cap Demand Forecast/TLine Cap Stock	dmnl	This is the fraction of total demand compared to capacity available. If \ it is less than 1 that means there is sufficient capacity available, if it \ is over 1 then there is a shortfall.	AUXILIARY
TLine Cap indicated orders	TLine Cap desired acq rate+TLine Cap adj for supply line	Miles/Year	Producers are seeking to correct the gap between the desired and actual \ supply line over the supply line adjustment time. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TLine Cap order cancellation	(TLine Cap on Order*TLine Cap avg percent cancel)	Miles/Year	New capacity on order that is cancelled each year. Cancellations come \ from a range of undesignated sources, such as changes in planning, or from \ the effect of the poor liquidity of	AUXILIARY

			the power company.	
TLine Cap order rate	MAX(0,TLine Cap indicated orders*Effect of PowerCo Liquidity on orders)	Miles/Year	Desired acquisition rate adjusted by the adequacy of the supply line. \ Source: Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling \ for a Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TLine Prob failure	TLine Cap effect on failure f(TLine Cap fraction)	dmnl	Estimation of the probability of failure due to the relative capacity of \ the transmission system.	AUXILIARY
Total HH	Total Population/Avg household	Households	Estimate of number of households based on average household size.	AUXILIARY
Total Population	Rur Population+Urb Population	People	Sum of rural and urban populations.	AUXILIARY
Trans Cap exp acq delay	TLine Cap acq delay	Years	This the expected dealy in acquisition of capacity, based on the estimated \ delay. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking and \ Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TSub Cap acquisition rate	DELAY3(TSub Cap order rate*Effect of PowerCo Liquidity on Acq, TSub Cap acq delay)	KVA/Year	The supply chain for capacity assumes a third-order capacity acquisition \ delay. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking and \ Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TSub Cap adj for capacity	(TSub Cap Demand Forecast-TSub Cap Stock)/TSub Cap adj time	KVA/Year	This is the adjustment in capacity demand based on the gap between desired \ stock and actual capacity. Source: Sterman, J. 2000. Business Dynamics: \ Systems Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw \ Hill.	AUXILIARY
TSub Cap adj for supply line	(TSub Cap desired supply line-TSub Cap on Order)/TSub Supply line adj time	KVA/Year	This is the capacity orders needed to fill the gap between desired \ capacity in supply line and actual capacity in the supply line. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TSub Cap Demand Forecast	Gen Energy Demand Forecast*TSub Cap requirement*kWh to GWh	KVA	Estimation of the number of miles of transmission line needed to carry the \ annual energy load of the system.	AUXILIARY
TSub Cap desired acq rate	TSub Cap expected discard rate+TSub Cap adj for capacity	KVA/Year	This is the replacement of espected iscards, adjusted in response to the \ gap between desired	AUXILIARY

			and actual capital stocks. Source: Sterman, J. 2000. \ Business Dynamics: Systems Thinking and Modeling for a Complex World. \ Chicago: Irwin-McGraw Hill.	
TSub Cap desired supply line	TSub Cap exp acq delay*TSub Cap desired acq rate	KVA	The amount of capacity the producer must have on order and under \ construction to yield the desired acquisition rate. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TSub Cap discard rate	DELAY3I(TSub Cap Stock/TSub Cap life of capacity+TSub Cap theft of capacity , TSub Cap discard delay\ , TSub Cap Stock/ TSub Cap life of capacity)	KVA/Year	This is the estimated total loss in capacity per year due to both decay of \ lines and theft of lines. Source: Sterman, J. 2000. Business Dynamics: \ Systems Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw \ Hill.	AUXILIARY
TSub Cap exp acq delay	TSub Cap acq delay	Years	This the expected dealy in acquisition of capacity, based on the estimated \ delay. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking and \ Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TSub Cap expected discard rate	TSub Cap discard rate	KVA/Year	This is the expected discard rate, based on the estimation of losses due \ to theft and retirment of equipment. Source: Sterman, J. 2000. Business \ Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: \ Irwin-McGraw Hill.	AUXILIARY
TSub Cap fraction	TSub Cap Demand Forecast/TSub Cap Stock	dmnl	This is the fraction of total demand compared to capacity available. If \ it is less than 1 that means there is sufficient capacity available, if it \ is over 1 then there is a shortfall.	AUXILIARY
TSub Cap indicated orders	TSub Cap desired acq rate+TSub Cap adj for supply line	KVA/Year	Producers are seeking to correct the gap between the desired and actual \ supply line over the supply line adjustment time. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TSub Cap order cancellations	(TSub Cap on Order*TSub Cap avg percent cancel)	KVA/Year	New capacity on order that is cancelled each year. Cancellations come \ from a range of	AUXILIARY

			undesignated sources, such as changes in planning, or from \ the effect of the poor liquidity of the power company.	
TSub Cap order rate	MAX(0,TSub Cap indicated orders*Effect of PowerCo Liquidity on orders)	KVA/Year	Desired acquisition rate adjusted by the adequacy of the supply line. \ Source: Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling \ for a Complex World. Chicago: Irwin-McGraw Hill.	AUXILIARY
TSub Prob failure	TSub Cap effect on failure f(TSub Cap fraction)	dmnl	Estimation of the probability of failure due to the relative capacity of \ the transmission system.	AUXILIARY
Urb Grid initial	Urb population initial*Urb Percent Grid initial	People	People in urban areas with access to electricity in 1995.	AUXILIARY
Urb PopGrowth	Urb Population*Urb Percent Growth	People/Year	Population growth based on assumed growth rate.	AUXILIARY
Urb population initial	Population initial*Urb Percent Pop initial	People	People living in rural areas in Kenya in 1995.	AUXILIARY
Urbanization	Rur Population*Urbanization rate	People/Year	Migration of rural population to urban areas, based on assumed \ urbanization rate.	AUXILIARY
Urbanization rate	DELAY3((Urbanization initial*Effect of Desired Percent Urban on Urbanization), Delay in Urban capacity perception\ )	1/Year	Rate of urbanization - initialized to 3.2%. Pace of urbanization slows as \ cities reach a carrying capacity. Source:	AUXILIARY
Utility Ind Options[Industrial options]	(Exp Ind Capex[Industrial options]/Ind Reference Capex*Sens Ind Capex)+(Exp Ind Reliability\ [Industrial options]*Sens Ind Reliability)+(Exp Ind Unit price [Industrial options]/Ind Reference Unit Price*Sens Ind Unit price)	dmnl	Calculates the utility of all industrial options based on the attributes \ of reliability, unit price, and capital costs.	AUXILIARY
Utility of Grid source[Grid sources]	(Expected Grid source MC[Grid sources]/Grid Source reference MC*Grid sensitivity to MC\ )+(Expected Grid source projected price[Grid sources]/Grid Source reference price*Grid sensitivity to projected price\ )	dmnl	Utility of grid generation options, used to determine the best source for \ capacity expansion.	AUXILIARY
Expected Grid	SMOOTH(Grid Source			AUXILIARY

source MC[Geotherm]	MC[Geotherm]*Effect of scarcity on geothermal, Perception delay Grid MC\ )			
Expected Grid source MC[Hydro]	SMOOTH(Grid Source MC[Hydro]*Effect of scarcity on hydro, Perception delay Grid MC)\			AUXILIARY
Expected Grid source MC[Import]	SMOOTH(Grid Source MC[Import], Perception delay Grid MC)	$/kW	This function smooths the transition in MC so it is perceived over time \ instead of instantly upon changing.	AUXILIARY
HH Growth[Urban]	Urb PopGrowth/Avg household	Households/ Year	Estimates the number of new households per year based on population growth \ and average household size.	AUXILIARY
Ind Capex[IndGrid]	Ind Grid connection	KSh/system	Capital cost in KSh for industrial off-grid installation or grid \ connection.	AUXILIARY
Ind Capex[IndOGHydro]	Ind Hydro system*Real exchange rate			AUXILIARY
Ind Capex[IndOGRenew]	Ind Renew system*Real exchange rate			AUXILIARY
Ind OffGrid Growth[IndOGHydro]	Ind kWh Total*Industrial Growth*Indicated share Ind Options[IndOGHydro]			AUXILIARY
Ind OffGrid Growth[IndOGRenew]	Ind kWh Total*Industrial Growth*Indicated share Ind Options[IndOGRenew]	(kilowatt*hour)/Year/Year	There is annual growth in off-grid unit "sales" based on the expected \ growth rate and the indicated market share for each of the off-grid \ options.	AUXILIARY
Ind OffGrid Units shifting[IndOGHydro]	Ind OffGrid kWh[IndOGHydro]*Ind Percent Potential shift			AUXILIARY
Ind OffGrid Units shifting[IndOGRenew]	Ind OffGrid kWh[IndOGRenew]*Ind Percent Potential shift	(kilowatt*hour)/Year/Year	Number of unit sales from each off-grid source which will potentially move \ to another source in a given year.	AUXILIARY
Ind Unit price[IndGrid]	Grid Indicated Ind Price	KSh/(kilowatt *hour)	Price per unit for all industrial power options, both grid and off-grid.	AUXILIARY

Ind Unit price[IndOGDiesel]	Ind Diesel unit price			AUXILIARY
Ind Unit price[IndOGHydro]	Ind Hydro unit price*Real exchange rate*Effect of scarcity on hydro			AUXILIARY
Res Capex[Population, ResGrid]	Res Grid connection	KSh/household	Cost of a small, home-scale generator system or grid connection.	AUXILIARY
Res Capex[Population, ResOGRenew]	Res Renew system*Real exchange rate			AUXILIARY
Res Perceived backlog[Rural,Res Grid]	ACTIVE INITIAL (Res HH Grid Backlog Ratio[Rural], 1)	dmnl	The perceived backlog to residential consumers is the fraction of demand \ for grid electricity currently going unmet. As this fraction increases, \ the customer's perception of the likelihood of being connected to the grid \ decreases and so the guaranteed off-grid options seem relatively more \ attractive.	AUXILIARY
Res Unit price[Population,ResOGDiesel]	Res Diesel unit price			AUXILIARY
Res Unit price[Population,ResOGRenew]	Res Renew unit price*Real exchange rate	KSh/(kilowatt*hour)	Unit price for all power options for residential consumers.	AUXILIARY
Switch Grid to OffGrid[IndOGHydro]	(Ind Grid Units shifting*Indicated share Ind Options[IndOGHydro])			AUXILIARY
Switch Grid to OffGrid[IndOGRenew]	(Ind Grid Units shifting*Indicated share Ind Options[IndOGRenew])	(kilowatt*hour)/Year/Year	Number of unit sales from grid customers that are switching to off-grid \ sources based on the indicated market share.	AUXILIARY
Switch in OffGrid to OffGrid[IndOGHydro]	((Ind OffGrid Units shifting[IndOGDiesel]+Ind OffGrid Units shifting[IndOGRenew])*Indicated share Ind Options\ [IndOGHydro])			AUXILIARY
Switch in OffGrid	((Ind OffGrid Units		This variable keeps track of the off-grid units	AUXILIARY

to OffGrid[IndOGRenew]	shifting[IndOGDiesel]+Ind OffGrid Units shifting[IndOGHydro])*Indicated share Ind Options\ [IndOGRenew])	(kilowatt*hour)/Year/Year	switching from one \ off-grid source to another. Specifically, it is a measure of the units \ moving, which move in to another off-grid source.	
Switch OffGrid to Grid[IndOGHydro]	(Ind OffGrid Units shifting[IndOGHydro]*Indicated share Ind Options[IndGrid])			AUXILIARY
Switch OffGrid to Grid[IndOGRenew]	(Ind OffGrid Units shifting[IndOGRenew]*Indicated share Ind Options[IndGrid])	(kilowatt*hour)/Year/Year	This variable keeps track of the units switching from off-grid sources to \ the grid, based on the number of units indicated to be considering another \ option and the indicated market share of grid generation.	AUXILIARY
Switch out OffGrid to OffGrid[IndOGHydro]	((Ind OffGrid Units shifting[IndOGHydro])*(Indicated share Ind Options[IndOGDiesel]+\ Indicated share Ind Options[IndOGRenew]))			AUXILIARY
Switch out OffGrid to OffGrid[IndOGRenew]	((Ind OffGrid Units shifting[IndOGRenew])*(Indicated share Ind Options[IndOGHydro]+Indicated share Ind Options\ [IndOGDiesel]))	(kilowatt*hour)/Year/Year	Combined with the variable Switch in OffGrid to OffGrid, this variable \ keeps track of movement between off-grid sources. It estimates the \ off-grid units switching in to other sources, based on the indicated \ market share of each.	AUXILIARY
Ind Renew system	(((Projected PV price+Kenya PV surcharge)/W to kW)+Ind PV Components cost)*Avg Ind Cap	$/system	Estimation of the capital cost of a renewable off-grid system, based on \ the cost per watt of PV and the estimated battery cost.	AUXILIARY
Switch out OffGrid to OffGrid[IndOGDiesel]	((Ind OffGrid Units shifting[IndOGDiesel])*(Indicated share Ind Options[IndOGHydro]+\ Indicated share Ind Options[IndOGRenew]))			AUXILIARY
Utility Res Options[Population , Residential options]	(Exp Res Backlog[Population,Residential options]*Sens Res Backlog)+(Exp Res Capex[Population\ ,Residential options]/Res Reference	dmnl	Calculates the expected utility of each of the residential options, \ segmented by population group, based on the attibutes of capex, unit \ price, reliability, and perception of backlog.	AUXILIARY

	Capex *Sens Res Capex)+(Exp Res Reliability[Population,Residential options]*Sens Res Reliability)+(Exp Res Unit price\ [Population,Residential options]/Res Reference Unit price*Sens Res Unit price)+(Perceived Quality of Connection[Population\ ,Residential options]*Sens Res Quality of Connection)			
Avg Grid Ind Specific fuel consumption	0.27	kg/(kilowatt*hour)	Source: Kenya Power & Lighting Company, Schedule of Rates, Part III Other \ Charges. Online: http://www.kplc.co.ke.	CONSTANT
Avg household	4.5	People/household	Average number of people per household in Kenya. This is will likely go \ down in the future, but unlikely that it will be by more than 1 person per \ household. Based on 1999 census data showing population of 28,686,607 in \ 6,371,370 households. Source: Kenya Central Bureau of Statistics. 2005. \ Statistical Abstract. Ministry of Planning and National Development.	CONSTANT
Avg Ind Cap	1000	kilowatt/system	Assumed value for average size of an industrial consumer in Kenya. Figure \ is based on interviews and data collected from Kenya Association of \ Manufacturers.	CONSTANT
Avg Res Cap[ResGrid]	0.25			CONSTANT
Avg Res kWh	360	(kilowatt*hour)/household/Year	Average annual consumption per household. KPLC estimates in Least Cost \ Development Plan pg. 9 that each new customer will use 1200 kWh per month, \ this does not match with findings from interviews or knowledge of \ customers. See Residential baseload explanation.	CONSTANT
Avg Res Specific Fuel Consumption	0.313	kg/(kilowatt*hour)	Fuel consumption for small generator. Souce: www.honda.com	CONSTANT

Base exchange rate	65	KSh/$	Kenya Power & Lighting Company, Schedule of Rates, Part III Other Charges. \ Online: http://www.kplc.co.ke.	CONSTANT
Base fuel cost Kenya	0.83	KSh/(kilowatt *hour)	Source: Kenya Power & Lighting Company, Schedule of Rates, Part III Other \ Charges. Online: http://www.kplc.co.ke.	CONSTANT
Base oil price KPLC	25	$/barrel	Price of oil used for Kenya Planning, based on KPLC Least Cost Development \ Plan. This variable is included for sensitivity testing to show how the \ planning is based on unrealistic expectations of the running cost of \ thermal power. Source: Kenya Power & Lighting Company. 2005. Least Cost \ Development Plan.	CONSTANT
Bias for shedding Res load	0.25	dmnl	Shows preference for shedding load first from domestic consumers, who will \ bear 75% of the load shedding. Estimation based on past experience with \ power failures in Kenya.	CONSTANT
Capacity discard delay	10	Years	Delay in initiating discards, assumes that no capacity is expiring \ immediately at the beginning of the model run.	CONSTANT
Delay in Urban capacity perception	5	Years	There is a delay in perception from when the urban areas reach their \ carrying capacity. Estimated at 5 years.	CONSTANT
Demand THRC	5	Year	Calibrated to fit demand data and estimated from descriptions in Sterman \ 2000, pg. 634-636. Source: Sterman, J. 2000. Business Dynamics: Systems \ Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
Demand TPPC	0.25	Year	Time to perceive present trend. Sterman 2000 pg. 634-636 Source: Sterman, \ J. 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	CONSTANT
Demand TPT	2	Year	Time to perceive trend. Sterman 2000 pg. 634-636 Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	CONSTANT
Density of diesel	0.85	kg/L	Source: Incropera, F. and D. DeWitt. 1996.	CONSTANT

			Fundamentals of Heat and Mass \ Transfer. John Wiley & Sons, New York.	
Desired Percent Urban	0.75	dmnl [0,1]	Assumed maximum sustainable urban population percentage. Above this \ figure, there will be a slowdown in the urbanization rate due to reduced \ quality of life in the city. Based on the UN data for percent urban in \ more developed regions. Source: Population Division of the Department of \ Economic and Social Affairs of the United Nations Secretariat, World \ Population Prospects: The 2006 Revision and World Urbanization Prospects: \ The 2007 Revision, http://esa.un.org/unup.	CONSTANT
ERB Delay in price regulation	5	Years [1,10]	Delay between new regulation of prices. Source:	CONSTANT
Gen Cap acq delay[Thermal]	1			CONSTANT
Gen Cap adj time	5	Years	This is the adjustment time needed for the demand to perceive the new \ capacity. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking \ and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
Gen Cap avg percent cancel	0.1	dmnl/Year	Percent of capacity orders canceled for reasons other than lack of cash \ flow to the power company.	CONSTANT
Gen Cap desired margin	0.3	dmnl	Goal of surplus capacity for reliable system operation. Source: Kenya \ Power & Lighting Company. 2005. Least Cost Development Plan.	CONSTANT
Gen cap initial[Thermal]	INITIAL(157)			CONSTANT
Gen Cap life of capacity[Thermal]	25			CONSTANT
Gen Supply line adj time	5	Years	This is the time taken to see the required supply line and make the order \ for new capacity. Source: Sterman, J. 2000. Business Dynamics: Systems \ Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
Geothermal initial	2000	MW	Estimated Geothermal potential. KenGen	CONSTANT

potential			estimates 2000 MW total available \ capacity. Source:	
Grid Energy Unit MC[Thermal]	0.05			CONSTANT
Grid ERB Levy	0.03	KSh/(kilowatt *hour) [0,0.1]	Fixed levy at 3 cents per kWh. Converted to KSh for the model, 0.03 \ KSh/kWh. Source: Kenya Power & Lighting Company, Schedule of Rates, Part \ III Other Charges. Online: http://www.kplc.co.ke.	CONSTANT
Grid Ind Base unit price initial	2	KSh/(kilowatt *hour)	Base unit price per kWh set by ERB. Estimated for calibration.	CONSTANT
Grid Losses	0.15	dmnl [0.01,1]	This is the estimated losses used by KPLC in calculations of price. \ Source: Kenya Power & Lighting Company, Schedule of Rates, Part III Other \ Charges. Online: http://www.kplc.co.ke.	CONSTANT
Grid OM Capacity MC[Thermal]	25			CONSTANT
Grid Ratio Res to Ind	1.2	dmnl [0.5,2]	Ratio of residential electricity price to industrial electricity price. \ Estimated from average ratio from 1995-2004 = 1.18 Explanation in \ appendix of thesis.	CONSTANT
Grid Res Base unit price initial	3.5	KSh/(kilowatt *hour)	Base charge per kWh set by ERB under Schedule of tariffs. Estimated for \ calibration.	CONSTANT
Grid sensitivity to MC	-20	dmnl	Estimates sensitivity of grid planners to changes in the projected \ marginal cost of capacity.	CONSTANT
Grid sensitivity to projected price	-5	dmnl	Estimates sensitivity of grid planners to changes in the projected price.	CONSTANT
Grid source base price[Thermal]	0.07			CONSTANT
Grid Source MC[Thermal]	150			CONSTANT
Grid Source reference MC	1000	$/kilowatt [0,600]	This reference cost normalizes the grid source marginal cost and makes the \ units	CONSTANT

			dimensionless for calculating the attractiveness and indicated \ market share.	
Grid Source reference price	10	KSh/(kilowatt *hour) [0,60]	Reference price per unit for normalization in grid generation planning.	CONSTANT
Grid VAT	0.18	dmnl [0,1]	Standing value added tax of 18% on all electricity energy consumed with an \ exemption of first 200 units under domestic consumption. For this model, \ the exemption is ignored. Source: Kenya Power & Lighting Company, \ Schedule of Rates, Part III Other Charges. Online: http://www.kplc.co.ke.	CONSTANT
Hydropower initial potential	2107.5	MW	This is the estimate of realistic hydropower capacity as estimated by the \ IEA Small hydro atlas (2008). As capacity is added, it is subtracted from \ the potential remaining. Source: Source: IEA. 2008. Small-Hydro Atlas: \ Kenya Country Brief. Online: \ http://www.small-hydro.com/index.cfm?Fuseaction	CONSTANT
Ind Diesel capex	620	$/kilowatt	Source: The World Bank. 2005. "Technical and Economic Assessment: Off Grid, \ Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
Ind Diesel OandM	0.035	$/(kilowatt*hour)	Estimated operations and maintenance cost for an off-grid industrial system. \ Source: The World Bank. 2005. "Technical and Economic Assessment: Off \ Grid, Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
Ind Grid connection	5.00E+07	KSh/system	Estimated from KPLC.	CONSTANT
Ind Hydro cost	1800	$/kilowatt	The industrial hydropower cost is the cost of installing a hydropower system for an \ average industrial consumer. Based on estimated cost per kW for mini-hydro \ system. Source: The World	CONSTANT

			Bank. 2005. "Technical and Economic \ Assessment: Off Grid, Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	
Ind Hydro unit price	0.05	$/(kilowatt*hour)	From price per unit for Mini hydro, ignoring levelized cost of capital since this \ model separates the capex from opex. Source: The World Bank. 2005. \ "Technical and Economic Assessment: Off Grid, Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
Ind Percent Potential shift	0.1	dmnl/Year [0,1]	Percent of market of industrial consumers re-considering their power \ options each year.	CONSTANT
Ind PV Components cost	15	$/kW	Estimate of cost of battery bank and charge controller for industrial \ scale off-grid PV system. Source: Based on interview data and price lists \ from Telesales Solar, Solagen Power, and Kassam Kanji (Mombasa) - all PV \ dealers in Kenya.	CONSTANT
Ind Reference Capex	1.00E+08	KSh/system	Reference capital cost used to normalize industrial capital costs and to \ make units dimensionless for calculation attractiveness and indicated \ market share.	CONSTANT
Ind Reference Unit Price	10	KSh/(kilowatt*hour)	This reference cost normalizes the industrial unit price and makes the \ units dimensionless for calculating the attractiveness and indicated \ market share.	CONSTANT
Ind Renew unit price	0.07	$/(kilowatt*hour)	Source: The World Bank. 2005. "Technical and Economic Assessment: Off Grid, \ Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
Industrial Growth	0.03	1/Year	Growth estimate from regressions analysis.	CONSTANT

			Source: Kenya Power & Lighting \ Company. 2005. Least Cost Development Plan.	
Interest rate on cash	0.03	dmnl/Year	Estimated return on cash investments.	CONSTANT
Interest rate on debt	0.15	dmnl/Year	Estimated interest rate on debts.	CONSTANT
Kenya PV surcharge	5	$/Watt	This surcharge represents the additional charge per Watt for PV in Kenya. \ This is likely due to inefficiencies in the supply chain and is derived \ from comparing the current cost of polychrystalline panels. Based on \ Kammen 1999, cost per Watt in Kenya was	CONSTANT
kW to kWh per year	7000	hour/Year	Converts capacity to yearly energy by multiplying by the number of hours \ in a year. 1 year	CONSTANT
kW to MW	0.001	MW/kW	Converts kW to MW. 1000 kW = 1 MW	CONSTANT
kWh to GWh	1.00E-06	(gigawatt*hour)/(kilowatt*hour)	Converts kWh values to GWh (and vice versa) 1 GWh=1000000 kWh	CONSTANT
Perceived Quality of Connection[Population,ResGrid]	1			CONSTANT
Percent desired connect Diesel	0	dmnl/Year [0,1]	Percent of diesel customers each year who would prefer to connect to the \ grid if possible. Initial assumption is 0, higher values used in scenario \ analysis.	CONSTANT
Percent desired connect Renew	0	dmnl [0,1]	Percent of renewable customers each year who would prefer to connect to \ the grid if possible. Initial assumption is 0, higher values used in \ scenario analysis.	CONSTANT
Percent of debt bailout	0.25	dmnl/Year [0,1]	Percent of total debt that is covered by the bailout or default. Set at \ 25% initially with the assumption that the government is helping KPLC stay \ solvent.	CONSTANT
Perception delay Grid MC	10	Years	Delay in perception of changes to the marginal cost of capacity additions.	CONSTANT

Perception delay Grid projected price	10	Years	Delay in perception of pricing as seen by the generation capacity planners.	CONSTANT
Perception delay Ind Capex	5	Years [0.25,40]	This is the delay in perception of a price change in capital costs. There \ is no data for this estimate so this is an assumed value relative to the \ other attributes. Since fixed capital costs are likely to not be \ monitored closely, there will be a longer delay in perception than with \ unit prices or reliability.	CONSTANT
Perception delay Ind Reliability	1	Years [0.25,40]	This is the delay in perception of a price change in capital costs. There \ is no data for this estimate so this is an assumed value relative to the \ other attributes. Since fixed capital costs are likely to not be \ monitored closely, there will be a longer delay in perception than with \ unit prices or capital costs.	CONSTANT
Perception delay Ind Unit price	2	Years [0.25,40]	This is the delay in perception of a price change in kWh prices. There is \ no data for this estimate so this is an assumed value relative to the \ other attributes. Since fixed capital costs are likely to not be \ monitored closely, there will be a longer delay in perception than with \ capital costs or reliability.	CONSTANT
Perception delay Res Backlog	5	Year [0.25,40]	This is the delay in perception of a backlog. There is no data for this \ estimate so this is an assumed value relative to the other attributes. \ Information about backlogs will spread anectdotally so there is likely to \ be a long delay when the backlog gets worse or improves before people \ start to perceive it differently. The delay is assumed to be the same for \ urban and rural populations.	CONSTANT
Perception delay Res Capex	2	Year [0.25,10]	This is the delay in perception of a price change in capital costs. There \ is no data for this estimate so this is an assumed value relative to the \ other attributes. Since fixed capital costs are likely to not be \ monitored closely, there will be a longer delay in perception than with \ unit prices or reliability. The delay is assumed to be the same for urban \	CONSTANT

			and rural populations.	
Perception delay Res Reliability	1	Year [0.25,6]	This is the delay in perception of a price change in reliability. There \ is no data for this estimate so this is an assumed value relative to the \ other attributes. Customers are assumed to only have a few month delay in \ perceiving a change in the system reliability. The delay is assumed to be \ the same for urban and rural populations.	CONSTANT
Perception delay Res Unit price	2	Year [0.25,10]	This is the delay in perception of a price change in unit prices. There \ is no data for this estimate so this is an assumed value relative to the \ other attributes. Customers recieve monthly bills however, so it is \ likely they will begin to see a change in values as "real" after only a \ few months. The delay is assumed to be the same for urban and rural \ populations.	CONSTANT
Population initial	INITIAL(2.738e+007)	People	Total population of Kenya in 1995. Source: Population Division of the \ Department of Economic and Social Affairs of the United Nations \ Secretariat, World Population Prospects: The 2006 Revision and World \ Urbanization Prospects: The 2007 Revision, http://esa.un.org/unup.	CONSTANT
PowerCo Connect success percent	0.75	dmnl [0,1]	This variable estimates the success of the power company at meeting the \ target for electrification. It represents the potential gap between the \ stated goal and the real capacity. If equal to 1, the company is meeting \ their full target.	CONSTANT
PowerCo Connect target[Rural]	50000			CONSTANT
PowerCo Corruption tax	0.1	dmnl [0,1]	This is an estimate of the percentage of cash flow that is lost to \ corruption. There is no real estimate of losses so this figure is tested \ using sensitivity analysis.	CONSTANT
PowerCo Debt Maturity	30	Year	Time to repay debt, set at 30 years based on loan agreement.	CONSTANT
PowerCo	0.05	dmnl	Fixed levy of 5% of revenue from unit sales, uses	CONSTANT

Expense Grid REP Levy			to pay for the Rural \ Electrification Programme (REP). Source: Kenya Power & Lighting Company, \ Schedule of Rates, Part III Other Charges. Online: http://www.kplc.co.ke.	
PowerCo Payroll	0.1	KSh/Year	Estimated portion of budget that goes to paying employees. Currently KPLC \ operates inefficiently so there is a high percentage, but as performance \ improves the percent of profits going to payroll should diminish. This \ decrease in payroll expenses is explored in the scenario testing. Source: \ Kenya Power and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	CONSTANT
PowerCo Percent Bills collected	0.85	dmnl [0,1]	This value is the percentage of bills collected from customers and \ represents the max revenue collected from the amount billed. It is \ estimated from reports about problems with bill collection, but cannot be \ verified. It is included as one potential corruption leak.	CONSTANT
PowerCo Percent Meters read	0.85	dmnl [0,1]	This is the percentage of meters read by KPLC in a billing period. It \ represents the max billable percentage of units sold and is based on data \ collected during a meter readers meeting in Nairobi in October 2006.	CONSTANT
PowerCo Taxes	0.2	dmnl [0,1]	Government taxes on power company revenue. Rough estimate from cash flow \ statements. Source: Kenya Power and Lighting Company. 2004. 2002/2003 \ Annual Report. http://www.kplc.co.ke.	CONSTANT
PowerCo Time to perceive cash flow	2	Year	Time for the power company to recognize changes in their available cash \ flow.	CONSTANT
Price paid for generation	2.3	KSh/(kilowatt *hour) [0,20]	This is the price KPLC invoices to generation companies. It is one of the \ expenses that is subtracted from the revenue stream for the power company. \	CONSTANT
Res AdoptionFraction[	0.05			CONSTANT

Rural]				
Res ContactRate[Rural]	10			CONSTANT
Res Diesel capex	800	$/kilowatt	Source: The World Bank. 2005. “Technical and Economic Assessment: Off Grid, \ Mini-Grid and Grid Electrification Technologies”. Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
Res Diesel OandM	0.05	$/(kilowatt*hour)	Estimated operations and maintenance cost for a residential scale off-grid diesel \ system. Source: The World Bank. 2005. “Technical and Economic \ Assessment: Off Grid, Mini-Grid and Grid Electrification Technologies”. Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
Res Grid connection	35000	KSh/household	Price estimated by KPLC under the Umeme Promotion.	CONSTANT
Res PV Components cost	125	$/household	This is the cost of a PV system battery, used in a residential PV system. \ Source: Based on interview data and price lists from Telesales Solar, \ Solagen Power, and Kassam Kanji (Mombasa) - all PV dealers in Kenya.	CONSTANT
Res Reference Capex	100000	KSh/household	This reference cost normalizes the residential capital cost and makes the \ units dimensionless for calculating the attractiveness and indicated \ market share.	CONSTANT
Res Reference Unit price	10	KSh/(kilowatt*hour)	This reference cost normalizes the residential unit price and makes the \ units dimensionless for calculating the attractiveness and indicated \ market share.	CONSTANT
Res Renew unit price	0.16	$/(kilowatt*hour)	Estimated cost per unit for small PV system. Source: The World Bank. 2005. \ “Technical and Economic Assessment: Off Grid, Mini-Grid and	CONSTANT

			Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	
Residential Baseload	8.00E+08	(kilowatt*hour)/Year [0,6e+009]	This figure was added to calibrate the growth in consumption of \ residential users. It assumes that there is a wealthy installed base of \ residential power consumers. This is done as a fixed number rather than \ increasing the average use per customer, because of the supply of heavy \ residential users is already connected and each future connection will \ likely be much smaller.	CONSTANT
Rur Percent Grid initial	0.06	dmnl	Percent of rural population in 1995 with access to electricity. Source: \ Karekezi 2004.	CONSTANT
Rur Percent Growth	0.0246	1/Year	Growth rate set to 1995-2000 value. Source: Population Division of the \ Department of Economic and Social Affairs of the United Nations \ Secretariat, World Population Prospects: The 2006 Revision and World \ Urbanization Prospects: The 2007 Revision, http://esa.un.org/unup.	CONSTANT
Rur Percent Pop initial	INITIAL(0.81)	dmnl	This is the percent of the popuilation living in rural areas in 1995. \ Source: Population Division of the Department of Economic and Social \ Affairs of the United Nations Secretariat, World Population Prospects: The \ 2006 Revision and World Urbanization Prospects: The 2007 Revision, \ http://esa.un.org/unup.	CONSTANT
Sens Ind Capex	-5	dmnl [-40,-1]	This variable controls how sensitive the customer is to changes in the \ given attribute. The more negative the variable (in this case), the more \ sensitive the consumer is to variations. This value was fixed relative to \ the sensitivity to price and reliability. Industrial consumers \ interviewed had a preference for reducing their operating costs, even if \ it meant paying the cost of installing a new generator.	CONSTANT
Sens Ind	15	dmnl [1,80]	This variable controls how sensitive the customer	CONSTANT

Reliability			is to changes in the \ given attribute. The more positive the variable (in this case), the more \ sensitive the consumer is to variations. Customers were assumed to be \ more sensitive to variable changes than to capital cost changes, but less \ sensitive than to changes in unit price.	
Sens Ind Unit price	-20	dmnl [-100,-1]	This variable controls how sensitive the customer is to changes in the \ given attribute. The more negative the variable (in this case), the more \ sensitive the consumer is to variations. Industrial consumers were \ observed to be very sensitive to changes in unit price. Although they \ would not necessarily act immediately (see Switching Time), they would be \ inclined to investigate other options.	CONSTANT
Sens Res Backlog	-30	dmnl [-50,-1]	This variable controls how sensitive the customer is to changes in the \ given attribute. The more negative the variable (in this case), the more \ sensitive the consumer is to variations. The sensititivities to each \ attribute are assumed to be the same for both rural and urban populations.	CONSTANT
Sens Res Capex	-5	dmnl [-40,-1]	This variable controls how sensitive the customer is to changes in the \ given attribute. The more negative the variable (in this case), the more \ sensitive the consumer is to variations. The sensititivities to each \ attribute are assumed to be the same for both rural and urban populations.	CONSTANT
Sens Res Quality of Connection	20	dmnl	This variable controls how sensitive the customer is to changes in the \ given attribute. The more negative the variable (in this case), the more \ sensitive the consumer is to variations. The sensititivities to each \ attribute are assumed to be the same for both rural and urban populations.	CONSTANT
Sens Res Reliability	25	dmnl [1,20]	This variable controls how sensitive the customer is to changes in the \ given attribute. The more positive the variable (in this case), the more \ sensitive the consumer is to variations. The	CONSTANT

			sensititivities to each \ attribute are assumed to be the same for both rural and urban populations.	
Sens Res Unit price	-30	dmnl [-200,-1]	This variable controls how sensitive the customer is to changes in the \ given attribute. The more negative the variable (in this case), the more \ sensitive the consumer is to variations. The sensititivities to each \ attribute are assumed to be the same for both rural and urban populations.	CONSTANT
Sub Cap Res requirement	712.5	KVA*Year/(gigawatt*hour)	Estimate for KVA required for a given level of energy distributed on a \ power system. Source: Baughman and Bottaro (1976)	CONSTANT
Sum of forex costs	100000	KSh/Year	Average value, estimated since real value is not known. Source: Kenya \ Power & Lighting Company, Schedule of Rates, Part III Other Charges. \ Online: http://www.kplc.co.ke.	CONSTANT
TLine Cap acq delay	5	Years	This is the delay in acquiring new transmission line capacity. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
TLine Cap adj time	5	Years	This is the time it takes for the decision-maker to adjust to the capacity \ additions. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking \ and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
TLine Cap avg percent cancel	0.1	dmnl/Year	Percent of capacity orders canceled for reasons other than lack of cash \ flow to the power company.	CONSTANT
TLine Cap cost of maintenance	1800	$/mile/Year [0,1000]	This cost represents the cost to the power company for maintaining the current \ transmission system. It is one of the expenses that will reduce the cash \ available for investment. Estimated from World Bank 2005, cost of \ transmission lines O&M is 2% of capital cost. Capital cost in this case \ is estimated as $90,000/mile, converted from $/km value. Source: The \ World Bank. 2005. "Technical and Economic Assessment: Off Grid, \ Mini-Grid and Grid	CONSTANT

			Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	
TLine Cap discard delay	10	Years	Delay in initiating discards, assumes that no capacity is expiring \ immediately at the beginning of the model run.	CONSTANT
TLine cap initial	INITIAL(1771.34)	Miles	Miles of transmission lines 220 kV or 132 kV. Source: Kenya Power and \ Lighting Company. 2004. 2002/2003 Annual Report. http://www.kplc.co.ke.	CONSTANT
TLine Cap life of capacity	50	Years	This is the estimate of the life of Transmission lines. Source: The World Bank. \ 2005. "Technical and Economic Assessment: Off Grid, Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
TLine Cap theft of capacity	5	Miles/Year	This is the loss of capacity due to theft of lines. More likely the theft \ is going to happen at the distribution lines (see articles from Daily \ Natio referenced in text), however there will be some loss to transmission \ system. This variable can not be absolutely known so it is estimated at \ 10 miles per year and can be evaluated in the uncertainty testing.	CONSTANT
TLine construction cost	90000	$/mile	Average for high voltage lines, calculated from $/km figure. Source: \ Kenya Power and Lighting Company 2006a. East African Master Plan, Draft. \ Internal document.	CONSTANT
TLine Supply line adj time	5	Years	This is the time it takes the decision maker to adjust to changes in the \ supply line. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking \ and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
Trans Cap requirement	0.1436	Miles*Year/(g	Source: Baughman, M. and D. Bottaro. 1976. "Electric power transmission and \ distribution	CONSTANT

		igawatt*hour)	systems: Costs and their allocation". IEEE Transactions on Power \ Apparatus and Systems. PAS-95(3).	
TSub Cap acq delay	5	Years	This is the delay in acquiring new transmission line capacity. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
TSub Cap adj time	5	Years	This is the time it takes for the decision-maker to adjust to the capacity \ additions. Source: Sterman, J. 2000. Business Dynamics: Systems Thinking \ and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
TSub Cap avg percent cancel	0.1	dmnl/Year	average percent of orders which are cancelled for reasons other than cash \ flow	CONSTANT
TSub Cap cost of maintenance	0.75	$/KVA/Year [0,1000]	This cost represents the cost to the power company for maintaining the current \ transmission system. It is one of the expenses that will reduce the cash \ available for investment. Estimated from World Bank 2005, cost of \ transmission lines O&M is 2% of capital cost. Capital cost in this case \ is estimated as $90,000/mile, converted from $/km value. Source: The \ World Bank. 2005. "Technical and Economic Assessment: Off Grid, \ Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \ http://go.worldbank.org/6RPPDH8GI0.	CONSTANT
TSub Cap discard delay	5	Years	Delay in initiating discards, assumes that no capacity is expiring \ immediately at the beginning of the model run.	CONSTANT
TSub Cap life of capacity	50	Years	This is the estimate of the life of Transmission lines. Source:The World Bank. 2005. \ "Technical and Economic Assessment: Off Grid, Mini-Grid and Grid Electrification Technologies". Discussion Paper. Energy Unit, \ Energy and Water Department. Available from: \	CONSTANT

			http://go.worldbank.org/6RPPDH8GI0.	
TSub Cap requirement	523.2	KVA*Year/(gigawatt*hour)	Estimate KVA required for a given level of energy distributed on a power \ system-Industrial value used. Source: Baughman, M. and D. Bottaro. 1976. \ "Electric power transmission and distribution systems: Costs and their allocation". IEEE Transactions on Power \ Apparatus and Systems. PAS-95(3).	CONSTANT
TSub Cap theft of capacity	10000	KVA/Year	This is the loss of capacity due to theft of lines. More likely the theft \ is going to happen at the distribution lines (see articles from Daily \ Natio referenced in text), however there will be some loss to transmission \ system. This variable can not be absolutely known so it is estimated at \ 10000 KVA per year and can be evaluated in the uncertainty testing.	CONSTANT
TSub construction cost	7.5	$/KVA	Estimated from capacity additions outline in EAMP. Source: Kenya Power \ and Lighting Company 2006a. East African Master Plan, Draft. Internal \ document.	CONSTANT
TSub Supply line adj time	5	Years	This is the time it takes the decision maker to adjust to changes in the \ supply line. Source: Sterman, J. 2000. Business Dynamics: Systems \ Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
Urb Percent Grid initial	0.173	dmnl	Percent of urban population in 1995 with access to electricity. Source: \ Karekezi 2004.	CONSTANT
Urb Percent Growth	0.0344	1/Year	Growth rate set to 1995-2000 figure. Source: Population Division of the \ Department of Economic and Social Affairs of the United Nations \ Secretariat, World Population Prospects: The 2006 Revision and World \ Urbanization Prospects: The 2007 Revision, http://esa.un.org/unup.	CONSTANT
Urb Percent Pop initial	INITIAL(0.19)	dmnl	This is the percent of the popuilation living in urban areas in 1995. \ Source: Population Division of the Department of Economic and Social \ Affairs of the United Nations Secretariat, World Population	CONSTANT

			Prospects: The \ 2006 Revision and World Urbanization Prospects: The 2007 Revision, \ http://esa.un.org/unup.	
Urbanization initial	0.032	1/Year [0,1]	Intercensul (1989-1999) urbanization rate for Kenya. Source: Kenya \ Central Bureau of Statistics. 2004. 1999 Population and Housing Census, \ Volume VI: Analytical Report on Migration and Urbanization. Ministry of \ Finance and Planning.	CONSTANT
W to kW	0.001	kilowatt/Watt	Converts W to kW. 1000 W = 1 kW	CONSTANT
World oil to Kenya oil	1.78	(KSh*barrel)/(L*$)	Factor based on the comparison of available data on pump prices in Kenya \ and World oil prices from 1995-2005. This factor is used as an \ approximation of the cost of distributing oil in Kenya. Documentation of \ the estimate is found in the appendix of the thesis.	CONSTANT
Avg Res Cap[ResOGDiesel]	0.3			CONSTANT
Avg Res Cap[ResOGRenew]	0.05	kilowatt/household	Average maximum capacity demand for residential consumers, used both to \ estimate necessary grid capacity and home power systems. Explanation of \ variation in comparative costs in report.	CONSTANT
Gen Cap acq delay[Geotherm]	5	Years	This is the delay in building capacity once it is on order. There is \ going to be a lot of variation in this, for example Sondo Miru has take 8 \ years to come online, but some of the thermal plants are much faster. \ Source (structure): Sterman, J. 2000. Business Dynamics: Systems Thinking \ and Modeling for a Complex World. Chicago: Irwin-McGraw Hill.	CONSTANT
Gen Cap acq delay[Hydro]	5			CONSTANT
Gen Cap acq delay[Import]	2			CONSTANT
Gen cap	115	MW	Total installed generation capacity in 1995.	CONSTANT

initial[Geotherm]			Source: Kenya Power and \ Lighting Company. 2004. 2002/2003 Annual Report. http://www.kplc.co.ke.	
Gen cap initial[Hydro]	496			CONSTANT
Gen cap initial[Import]	50			CONSTANT
Gen Cap life of capacity[Geotherm]	25	Years	This is the estimated life of a thermal plant in Kenya, according to the \ KPLC Least Cost Development Plan Update (2005). Values found in Table \ 4.8(Thermal), Table 4.2(Hydro), Table 4.7 (Geothermal), and 4.2 (Imports). \ Kenya Power & Lighting Company. 2005. Least Cost Development Plan.	CONSTANT
Gen Cap life of capacity[Hydro]	50			CONSTANT
Gen Cap life of capacity[Import]	50			CONSTANT
Grid Energy Unit MC[Geotherm]	0.001	$/(kilowatt*hour) [0,1]	Marginal cost of energy, as estimated in the KPLC LCDP. Source: Kenya \ Power & Lighting Company. 2005. Least Cost Development Plan.	CONSTANT
Grid Energy Unit MC[Hydro]	0.001			CONSTANT
Grid Energy Unit MC[Import]	0.001			CONSTANT
Grid OM Capacity MC[Geotherm]	30	$/(kilowatt*Year)	Marginal cost of capacity for plants in use. This is the cost of \ operation and maintenance for the different sources of grid generation. \ Source: Kenya Power & Lighting Company. 2005. Least Cost Development Plan.	CONSTANT
Grid OM Capacity MC[Hydro]	12			CONSTANT
Grid OM Capacity MC[Import]	0			CONSTANT
Grid source base price[Geotherm]	0.04			CONSTANT

Grid source base price[Hydro]	0.09			CONSTANT
Grid source base price[Import]	0.025	$/(kilowatt*hour)	O&M cost per unit for grid sources. Source: Kenya Power & Lighting \ Company. 2005. Least Cost Development Plan.	CONSTANT
Grid source fuel cost[Geotherm]	0	KSh/(kilowatt*hour)	Fuel cost for thermal generation based on grid fuel use, other subscripts \ used as placeholders.	CONSTANT
Grid source fuel cost[Hydro]	0			CONSTANT
Grid source fuel cost[Import]	0			CONSTANT
Grid Source MC[Geotherm]	385			CONSTANT
Grid Source MC[Hydro]	350			CONSTANT
Grid Source MC[Import]	307	$/kilowatt [0,800]	These are the marginal costs of capacity for each of the types of \ generation source. Source: Kenya Power & Lighting Company. 2005. Least \ Cost Development Plan.	CONSTANT
Ind Reliability[IndOGDiesel]	0.95			CONSTANT
Ind Reliability[IndOGHydro]	0.95			CONSTANT
Ind Reliability[IndOGRenew]	0.95	dmnl	Probability of no failure for both grid and off-grid options. The value \ represents the probability of having electricity when you want it. For \ the grid option, this is based on the variable "Grid Reliability", and for \ the off-grid options the value is estimated as .95 to approximate some \ unplanned failures.	CONSTANT
Perceived Quality of Connection[Population,ResOGDiesel]	0.25			CONSTANT

Perceived Quality of Connection[Population,ResOGRenew]	0.5	dmnl	Variable added to estimate the perceived quality of the connection to grid \ vs. the off-grid options. This a highly subjective estimate, but based on \ interview data suggesting that grid is seen as far superior because it is \ "modern". This perception was also noted in Steel (2003) for rural \ villagers in South Africa. Grid is perceived as the highest quality, with \ solar PV second, and diesel last because of the noise and smell. The \ inclusion of this variable helps normalize the "apples to oranges" \ comparison between size of connection. See variable "Res Capex".	CONSTANT
PowerCo Connect target[Urban]	100000	Households/ Year [0,400000]	This is the target set by the power company for new grid connections in a \ given year. It is subscripted to reflect separate goals for urban and \ rural customers. The figures are set to KPLC's current target of 150,000 \ total new connections per year. Source: Interviews with KPLC personnel, \ split between rural and urban is estimated.	CONSTANT
Res AdoptionFraction[Urban]	0.1	dmnl [0,1]	Percent of population that will purchase electricity after they have seen \ the benefit. No data to support, so estimated value.	CONSTANT
Res ContactRate[Urban]	20	Households/household/Year [0,100]	Number of contacts with other households, per household. There is no data \ for this value, so it is assumed.	CONSTANT
Res Perceived backlog[Population, ResOGDiesel]	1, 1			CONSTANT
Res Perceived backlog[Population, ResOGRenew]	1, 1			CONSTANT
Res Reliability[Population,ResOGDiesel]	0.95			CONSTANT
Res Reliability[Populati	0.95	dmnl	Probability of no failure for grid and off-grid options. The value \ represents the probability of	CONSTANT

on,ResOGRenew]			having electricity when you want it. For \ the grid option, this is based on the variable "Grid Reliability", and for \ the off-grid options the value is estimated as .95 to approximate some \ unplanned failures.	
Demand PPC	INTEG (Demand Change in PPC, Gen Cap Demand/(1+Demand TPPC*Industrial Growth))	MW	Present percieved condition of demand. Source: Sterman, J. 2000. Business \ Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: \ Irwin-McGraw Hill.	LEVEL
Demand RC	INTEG (Demand Change in RC, (Gen Cap Demand/(1+Demand TPPC*Industrial Growth))/(1+Demand THRC*Industrial Growth\ ))	MW	Reference condition for predicting demand growth. Source: Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	LEVEL
Demand TREND	INTEG (Demand Change in TREND, Industrial Growth)	1/Year	output of trend is fractional growth rate per time period. Source: \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	LEVEL
Gen Cap on Order[Thermal]	INTEG (Gen Cap order rate[Thermal]-Gen Cap acquisition rate[Thermal]-Gen Cap order cancellations\ [Thermal], 200)			LEVEL
Gen Cap Stock[Thermal]	INTEG (Gen Cap acquisition rate[Thermal]-Gen Cap discard rate[Thermal], Gen cap initial[Thermal])			LEVEL
Geothermal potential	INTEG (-Geotherm Cap additions, Geothermal initial potential-Gen cap initial[Geotherm])	MW	Estimated remaining geothermal potential. Source: Business Council for \ Sustainable Development (BCSD). 2003. Market Assessment Report. Eastern \ Africa Geothermal Market Acceleration Conference. Online: \ www.bcse.org/adobefiles/marketreport.pdf	LEVEL
Hydropower potential	INTEG (-Hydro Cap additions, Hydropower initial potential-Gen cap initial[Hydro])	MW	This is the estimate of remaining hydropower capacity. As capacity is \ added, it is subtracted from the potential remaining.	LEVEL
Ind Grid kWh	INTEG (Ind Grid Growth[IndGrid]+Switch OffGrid to	(kilowatt*hour	Industrial grid units sold. Initialized using value from 1995. Source \ (initial value): Kenya Power	LEVEL

	Grid[IndOGDiesel]+Switch OffGrid to Grid[\ IndOGHydro]+Switch OffGrid to Grid[IndOGRenew]-Switch Grid to OffGrid[IndOGDiesel]-Switch Grid to OffGrid[IndOGHydro]-Switch Grid to OffGrid\ [IndOGRenew], 2.109e+009)	)/Year	and Lighting Company. 2004. 2002/2003 Annual \ Report. http://www.kplc.co.ke.	
Ind OffGrid kWh[IndOGDiesel]	INTEG (Ind OffGrid Growth[IndOGDiesel]+Switch Grid to OffGrid[IndOGDiesel]+Switch in OffGrid to OffGrid\ [IndOGDiesel]-Switch OffGrid to Grid[IndOGDiesel]-Switch out OffGrid to OffGrid[IndOGDiesel\ ], 100000)			LEVEL
PowerCo Debt	INTEG (PowerCo Shortfall-Default or bailout-PowerCo Repayment, 5e+009)	KSh	Estimated outstanding debt for the power company. This debt must be \ repaid over the course of the repayment period. The debt is either \ repayed or is defaulted or paid by an external source. Debt is \ initialized at 5B KSh, assuming there would already be debt in the \ pipeline at 1995.	LEVEL
Res HH Grid[Rural]	INTEG (Grid Connections[Rural]+Grid Connections from Diesel[Rural]+Grid Connections from Renew\ [Rural], Rur Grid initial/Avg household)			LEVEL
Res HH NoElec[Rural]	INTEG (HH Growth[Rural]-Grid Connections[Rural]-OffGrid Diesel Sales[Rural]-OffGrid Renew Sales\ [Rural], (Rur population initial-Rur Grid initial)/Avg household)			LEVEL
Res HH OffGrid Diesel[Rural]	INTEG (OffGrid Diesel Sales[Rural]-Grid Connections from Diesel[Rural], 10000)			LEVEL

Res HH OffGrid Renew[Rural]	INTEG (OffGrid Renew Sales[Rural]-Grid Connections from Renew[Rural], 10000)			LEVEL
Rur Population	INTEG (Rur PopGrowth-Urbanization, Rur population initial)	People	Total population living in rural areas.	LEVEL
TLine Cap on Order	INTEG (TLine Cap order rate-TLine Cap acquisition rate-TLine Cap order cancellation, 250)	Miles	This is the orders for new transmission capacity already in the pipeline \ at the initial time of the model. It is initialized at 250, an assumption \ that there is capacity on order in 1995. Source (structure): Sterman, J. \ 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill.	LEVEL
TLine Cap Stock	INTEG (TLine Cap acquisition rate-TLine Cap discard rate, 1771.34)	Miles	This is the capital stock currently in use. It is initialized to the 1995 \ value for number of miles of transmission line. Source: Kenya Power and \ Lighting Company. 2004. 2002/2003 Annual Report. http://www.kplc.co.ke.	LEVEL
TSub Cap on Order	INTEG (TSub Cap order rate-TSub Cap acquisition rate-TSub Cap order cancellations, 50000)	KVA	This is the orders for new transmission capacity already in the pipeline \ at the initial time of the model. It is initialized at 50000, an \ assumption that there is capacity on order in 1995. Source (structure): \ Sterman, J. 2000. Business Dynamics: Systems Thinking and Modeling for a \ Complex World. Chicago: Irwin-McGraw Hill.	LEVEL
TSub Cap Stock	INTEG (TSub Cap acquisition rate-TSub Cap discard rate, 2.24e+006)	KVA	This is the capital stock currently in use. It is initialized to the 1995 \ value for transmission KVA. Source: KPLC Annual Report. Source \ (structure): Sterman, J. 2000. Business Dynamics: Systems Thinking and \ Modeling for a Complex World. Chicago: Irwin-McGraw Hill. Source (initial \ values): Kenya Power and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LEVEL
Urb Population	INTEG (Urb PopGrowth+Urbanization, Urb population initial)	People	Total population living in urban areas.	LEVEL

Gen Cap on Order[Geotherm]	INTEG (Gen Cap acquisition rate[Geotherm]+Gen Cap order rate[Geotherm]-Gen Cap order cancellations\ [Geotherm], 100)	MW	This is the capacity orders that are in the pipeline waiting to be built. \ The values are initialized at the quantity of the next planned capacity \ addition. Source (structure): Sterman, J. 2000. Business Dynamics: \ Systems Thinking and Modeling for a Complex World. Chicago: Irwin-McGraw \ Hill. Source (initial values): Kenya Power & Lighting Company. 2005. \ Least Cost Development Plan.	LEVEL
Gen Cap on Order[Hydro]	INTEG (Gen Cap acquisition rate[Hydro]+Gen Cap order rate[Hydro]-Gen Cap order cancellations\ [Hydro], 400)			LEVEL
Gen Cap on Order[Import]	INTEG (Gen Cap acquisition rate[Import]+Gen Cap order rate[Import]-Gen Cap order cancellations\ [Import], 50)			LEVEL
Gen Cap Stock[Geotherm]	INTEG (Gen Cap acquisition rate[Geotherm]-Gen Cap discard rate[Geotherm], Gen cap initial[Geotherm])	MW	Total stock of generation capacity feeding into the national power grid. \ This includes all generation sources and both KenGen and IPPs. \ Initialized to initial capital stock values. Source (structure): Sterman, \ J. 2000. Business Dynamics: Systems Thinking and Modeling for a Complex \ World. Chicago: Irwin-McGraw Hill. Source (initial values): Kenya Power & \ Lighting Company. 2005. Least Cost Development Plan.	LEVEL
Gen Cap Stock[Hydro]	INTEG (Gen Cap acquisition rate[Hydro]-Gen Cap discard rate[Hydro], Gen cap initial[Hydro])			LEVEL
Gen Cap Stock[Import]	INTEG (Gen Cap acquisition rate[Import]-Gen Cap discard rate[Import], Gen cap initial[Import])			LEVEL
Ind OffGrid kWh[IndOGHydro]	INTEG (Ind OffGrid Growth[IndOGHydro]+Switch Grid to OffGrid[IndOGHydro]+Switch in OffGrid to OffGrid\ [IndOGHydro]-			LEVEL

	Switch OffGrid to Grid[IndOGHydro]-Switch out OffGrid to OffGrid[IndOGHydro\ ], 500000)			
Ind OffGrid kWh[IndOGRenew]	INTEG (Ind OffGrid Growth[IndOGRenew]+Switch Grid to OffGrid[IndOGRenew]+Switch in OffGrid to OffGrid\ [IndOGRenew]-Switch OffGrid to Grid[IndOGRenew]-Switch out OffGrid to OffGrid[IndOGRenew\ ], 0)	(kilowatt*hour)/Year	The number of units generated off-grid for industrial use. \ Initializations are estimates.	LEVEL
Res HH Grid[Urban]	INTEG (Grid Connections[Urban]+Grid Connections from Diesel[Urban]+Grid Connections from Renew\ [Urban], Urb Grid initial/Avg household)	Households	This variable represents the number of households, both urban and rural, \ which are connected to grid electricity. It is the sum of all connections \ from the population without electricity and the PV and diesel system \ owners who later connected to the grid. Initialized from model variables \ on 1995 data.	LEVEL
Res HH NoElec[Urban]	INTEG (HH Growth[Urban]-Grid Connections[Urban]-OffGrid Diesel Sales[Urban]-OffGrid Renew Sales\ [Urban], (Urb population initial-Urb Grid initial)/Avg household)	Households	Initialized using 1995 data. See variables used for source.	LEVEL
Res HH OffGrid Diesel[Urban]	INTEG (Grid Connections from Diesel[Urban]+OffGrid Diesel Sales[Urban], 5000)	Households	Number of households using a diesel generator as the electric power \ supply. No data on sales estimat so variable is initialized at same level \ as PV as an approximation.	LEVEL
Res HH OffGrid Renew[Urban]	INTEG (Grid Connections from Renew[Urban]+OffGrid Renew Sales[Urban], 0)	Households	Total households, both urban and rural, who get their electricity from a \ PV system. Source(initial value): van der Plas, R. and M. Hankins.1998. \ "Solar Energy in Africa: a Reality". Energy Policy.26(4) pp. 295-305.	LEVEL
Demand hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'H2' \ )	MW	This is the peak demand on the grid system in a year. Source: Kenya Power \ and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LOOKUP

Dieselprice hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'O2' \ )	KSh/L	This is the price paid at the pump for diesel fuel in Kenya. Source: \ Kenya Central Bureau of Statistics. 2006. Leading Economic Indicators. \ Ministry of Planning and National Development.	LOOKUP
Effect of PowerCo Liquidity on Acq f([(0,0)-(10,1)],(0,0),(0.550459,0.144737),(1.02752,0.307018),(1.40367,0.539474),(1.70642\,0.719298),(2.20183,0.868421),(2.68807,0.95614),(3,1),(5,1),(10,1))		dmnl	Function used to generate a factor to reduce capacity acquisition based on \ lack of cash flow.	LOOKUP
Effect of PowerCo Liquidity on Orders f([(0,0)-(2,1)],(0,0),(0.159021,0.0701754),(0.360856,0.298246),(0.458716,0.495614),(0.556575\,0.679825),(0.66055,0.833333),(0.740061,0.921053),(0.831804,0.960526),(1,1),(1,1),(\1,1),(1,1),(1.41284,1),(1.91743,1))		dmnl	If the power company's cash flow is negative it creates a delay in \ capacity acquisition. This function estimates the magnitude of the delay. \ See report for full explanation of relationship between cash flow and \ investment.	LOOKUP
Gen Cap effect on failure f([(0,0)-(1000,1)],(0,0.001),(0.5,0.01),(0.8,0.1),(1.25382,0.26315		dmnl	This estimates the probability of failure based on the relative capacity. \ The probability is that of failure being experienced by a single agent at \ any time, so it accounts for rationing. Otherwise it would be binary. \ Need more explanation on this.	LOOKUP

8),(2.62997,0.455263\ ),(10,0.785088),(58.104,0.899123),(107.034,0.95614),(1000,0.98))				
Gen Cap hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'G2' \ )	MW	Total generation capacity (in MW) on the grid system. Source: Kenya Power \ and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LOOKUP
Ind cons hist :	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'C2' \ )	(kilowatt*hour)/Year	This is the historical electricity sales to industrial consumers. Source: \ Kenya Power and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LOOKUP
Ind Grid price hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'F2' \ )	KSh/(kilowatt*hour)	Industrial unit price charged to customers for 1995-2005. Source: Kenya \ Power and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LOOKUP
Projected LCDP[Thermal]:	GET XLS DATA('Kenya power model data.xls', 'Projected LCDP' , 'A' , 'B2')			LOOKUP
Projected oil price:	GET XLS DATA('Kenya power model data.xls', 'Projected oil price' , 'A' , 'B2')	$/barrel	This is the projected reference case for oil prices as projected by EIA. \ The low and high projections can be used by calling columns C2 and D2, \ respectively. Historial Source: Energy Information Administration (EIA). \ 2006. International Energy Annual 2004. Online: www.eia.doe.gov/iea. \ Projections Source: Energy Information Administration (EIA). 2006. \ International Energy Annual 2004. Online: www.eia.doe.gov/iea.	LOOKUP
Projected Percent Population in poverty[Rural]:	GET XLS DATA('Kenya power model data.xls', 'Projected poverty' , 'A' , 'B2')			LOOKUP
Projected PV price:	GET XLS DATA('Kenya power model data.xls', 'Projected PV price' , 'A' , 'B2')	$/Watt	This is the projected price per watt of photovoltaics in the future based \ on the assumed learning curve for PV. Source:	LOOKUP

Real exchange rate:	GET XLS DATA('Kenya power model data.xls', 'Real exchange rate' , 'A' , 'B2')	KSh/$	This is the real and projected exchange rate used to convert between \ Kenyan shilings and US dollars. Source: \ http://www.globalfinancialdata.com/index.php3?action=6136	LOOKUP
Res cons hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'B2' \ )	(kilowatt*hour)/Year	This is the historical electricity sales to residential consumers. \ Source: Kenya Power and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LOOKUP
Res Grid price hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'E2' \ )	KSh/(kilowatt*hour)	Residential unit price charged to customers for 1995-2005. Source: Kenya \ Power and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LOOKUP
Scarcity cost of geotherm f([(0,0)-(1,10)],(0,10),(0.0336391,8.59649),(0.0733945,7.36842),(0.119266,5.61404),(0.186544\ ,3.37719),(0.25,2),(0.3,1.5),(0.4,1.1),(0.5,1),(0.75,1),(1,1))		dmnl	Cost curve for additiona cost factor for geothermal based on scarcity of \ resource. No data available so curve is estimated.	LOOKUP
Scarcity cost of hydro f([(0,0)-(1,100)],(0,100),(0.0764526,96.9298),(0.12844,94.2982),(0.186544,85.9649),(0.232416\ ,68.8596),(0.281346,49.1228),(0.336391,32.8947),(0.382263,22.3684),(0.437309,13.1579\ ),(0.510703,5.2631		dmnl	Cost curve for additiona cost factor for hydropower based on scarcity of \ resource. No specific data so curve is estimated based on assumed range \ of economical hydropower. Source: IEA. 2008. Small-Hydro Atlas: Kenya \ Country Brief. Online: \ http://www.small-hydro.com/index.cfm?Fuseaction=49	LOOKUP

6),(0.599388,3.07018),(0.678899,2.19298),(0.785933,2.19298),(1,1)\ )				
TLine Cap effect on failure f([(0.4,0)-(10,1)],(0.414679, 0.00350877),(0.737615,0.122807),(1.08012,0.449123),(2.04404\ ,0.741228),(10,0.986842))		dmnl	This estimates the probability of failure based on the relative capacity. \ The probability is that of failure being experienced by a single agent at \ any time, so it accounts for rationing. Otherwise it would be binary. \ Need more explanation on this.	LOOKUP
TLine Cap hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'L2' \ )	Miles	The required capacity was based on transmission lines and substations. \ These are lines rated at 132 kV or 220 kV and substations rated at 132/220 \ kV, 220/132 kV, 220/66 kV, 132/66 kV, and 132/33 kV. Source: Kenya Power \ and Lighting Company. 2004. 2002/2003 Annual Report. \ http://www.kplc.co.ke.	LOOKUP
TSub Cap effect on failure f([(0.4,0)-(10,1)],(0.414679, 0.00350877),(0.737615,0.122807),(1.08012,0.449123),(2.04404\ ,0.741228),(10,0.986842))		dmnl	This estimates the probability of failure based on the relative capacity. \ The probability is that of failure being experienced by a single agent at \ any time, so it accounts for rationing. Otherwise it would be binary. \ Need more explanation on this.	LOOKUP
TSub Cap hist:	GET XLS DATA('Kenya power model data.xls', 'Historical data 1995-2005' , 'A' , 'I2' \ )	KVA	The required capacity was based on transmission lines and substations. \ These are lines rated at 132 kV or 220 kV and substations rated at 132/220 \ kV, 220/132 kV, 220/66 kV, 132/66 kV, and 132/33 kV. Source: Kenya Power \ and Lighting Company. 2004. 2002/2003 Annual Report. \	LOOKUP

			http://www.kplc.co.ke.	
Urban capacity effect f([(0.4,0)-(2,1)],(0.5,1),(0.669113,0.934211),(0.85,0.75),(1,0.530702),(1.07523,0.394737\ ),(1.32966,0.122807),(1.53517,0.0131579))	dmnl	As the percent of population in urban areas approaches the carrying \ capacity, this function produces a factor which is used to slow the rate \ of urbanization.		LOOKUP
Projected LCDP[Geotherm]:	GET XLS DATA('Kenya power model data.xls', 'Projected LCDP' , 'A' , 'C2')	MW	Projected capacity additions based on Kenya's plan through 2025. \ Estimated from base oil price and use for comparision and calibration of \ model capacity additions. Source: Kenya Power & Lighting Company. 2005. \ Least Cost Development Plan.	LOOKUP
Projected LCDP[Hydro]:	GET XLS DATA('Kenya power model data.xls', 'Projected LCDP' , 'A' , 'D2')			LOOKUP
Projected LCDP[Import]:	GET XLS DATA('Kenya power model data.xls', 'Projected LCDP' , 'A' , 'E2')			LOOKUP
Projected Percent Population in poverty[Urban]:	GET XLS DATA('Kenya power model data.xls', 'Projected poverty' , 'A' , 'C2')	dmnl	Projected percent of the population below the poverty line. Source: Kenya \ Central Bureau of Statistics. 2000. 1999 Population and Housing Census, \ Volume I: Incidence and Depth of Poverty. Ministry of Finance and Planning.	LOOKUP
Grid sources: Thermal, Hydro, Import, Geotherm		dmnl	This subscript keeps track of the options available to the power company \ for grid generation. The options are Thermal, Hydropower, Imports, and \ Geothermal. Renewables are not being considered on a large scale so are \ not included in the	SUBSCRIPT

			model, although an additional subscript could be added \ later to reflect this.	
Industrial options: IndGrid, IndOGDiesel, IndOGHydro, IndOGRenew		dmnl	This subscript classifies the options available to industrial consumers. \ The options are Grid, Off grid Diesel power, Off grid Hydropower, and Off \ grid Renewables (modeled here as PV).	SUBSCRIPT
Population: Rural, Urban		People	This subscript divides the residential population into rural and urban \ segments.	SUBSCRIPT
Resid options: ResGrid, ResOGDiesel, ResOGRenew		dmnl	Subscript to keep track of options available to residential customers.	SUBSCRIPT
Residential options: ResGrid, ResOGDiesel, ResOGRenew		dmnl	This subscript keeps track of the options available to residential \ consumers. The options are Grid, Off grid Diesel, and Off grid Renewables \ (modeled here as PV). The options are the same for both Rural and Urban \ consumers.	SUBSCRIPT

Model data inputs

Oil and PV price

Year	Oil Reference (US$/barrel)	Oil Low (US$/barrel)	Oil High (US$/barrel)	PV (US$/Watt)
1995	22.5	22.5	22.5	4.25
1996	26.6	26.6	26.6	4.20
1997	24.3	24.3	24.3	4.15
1998	16.8	16.8	16.8	4.10
1999	22.3	22.3	22.3	4.05
2000	34.2	34.2	34.2	4.00
2001	28.6	28.6	28.6	3.78
2002	28.3	28.3	28.3	3.57
2003	32.9	32.9	32.9	3.37
2004	42.9	42.9	42.9	3.18
2005	56.8	56.8	56.8	3.01
2006	69.1	69.1	69.1	2.84
2007	66.7	66.7	66.7	2.68
2008	64.1	61.9	66.9	2.53
2009	60.9	55.6	67.7	2.38
2010	57.5	49.2	69.2	2.25
2011	54.3	43.5	71.1	2.12
2012	51.7	38.7	72.6	2.00
2013	50.0	36.4	74.7	1.89
2014	49.6	35.1	77.2	1.78
2015	49.9	34.0	79.6	1.68
2016	49.7	33.8	81.9	1.58
2017	50.8	33.9	83.7	1.49
2018	51.3	34.0	85.5	1.41
2019	52.0	34.1	87.3	1.33
2020	52.0	34.1	89.1	1.25
2021	52.7	34.3	90.3	1.25
2022	53.4	34.4	91.0	1.25
2023	54.9	34.6	92.1	1.25
2024	55.6	34.7	93.3	1.25
2025	56.4	34.9	94.4	1.25
2026	57.1	35.0	95.5	1.25
2027	57.6	35.2	96.7	1.25
2028	58.1	35.4	97.8	1.25
2029	58.6	35.5	99.0	1.25
2030	59.1	35.7	100.1	1.25

Exchange rate and poverty estimate

Year	KSh/US$	Percent below poverty line-Rural (%)	Percent below poverty line-Urban (%)
1995	55.95	0.53	0.49
1996	54.95	0.53	0.49
1997	62.80	0.53	0.49
1998	61.55	0.53	0.49
1999	72.70	0.53	0.49
2000	77.95	0.53	0.49
2001	78.45	0.53	0.49
2002	77.40	0.53	0.49
2003	75.90	0.53	0.49
2004	78.50	0.53	0.49
2005	72.35	0.53	0.49
2006	69.55	0.53	0.49
2007	68.30	0.53	0.49
2008	68.30	0.53	0.49
2009	68.30	0.53	0.49
2010	68.30	0.53	0.49
2011	68.30	0.53	0.49
2012	68.30	0.53	0.49
2013	68.30	0.53	0.49
2014	68.30	0.53	0.49
2015	68.30	0.53	0.49
2016	68.30	0.53	0.49
2017	68.30	0.53	0.49
2018	68.30	0.53	0.49
2019	68.30	0.53	0.49
2020	68.30	0.53	0.49
2021	68.30	0.53	0.49
2022	68.30	0.53	0.49
2023	68.30	0.53	0.49
2024	68.30	0.53	0.49
2025	68.30	0.53	0.49
2026	68.30	0.53	0.49
2027	68.30	0.53	0.49
2028	68.30	0.53	0.49
2029	68.30	0.53	0.49
2030	68.30	0.53	0.49

Historical data

Year	Residential sales (kWh/year)	Industrial sales (kWh/year)	Total sales (kWh/year)	Residential price (KSh/kWh)	Industrial price (KSh/kWh)
1995	1,049,000,000	2,109,000,000	3,158,000,000	4.06	4.23
1996	1,116,000,000	2,193,000,000	3,309,000,000	5.33	4.27
1997	1,207,000,000	2,191,000,000	3,398,000,000	5.32	4.48
1998	1,270,000,000	2,193,000,000	3,463,000,000	5.22	4.64
1999	1,158,000,000	2,122,000,000	3,280,000,000	7.76	6.13
2000	1,064,000,000	1,970,000,000	3,034,000,000	9.74	8.36
2001	1,215,000,000	2,209,000,000	3,424,000,000	8.25	6.4
2002	1,283,000,000	2,305,000,000	3,588,000,000	6.89	5.62
2003	1,376,000,000	2,502,000,000	3,878,000,000	6.44	5.24
2004	1,478,000,000	2,661,000,000	4,139,000,000	7.03	6.13

Year	Generation capacity (MW)	Generation demand (MW)	Distribution capacity (KVA)	Transmission capacity (Miles)
1995	818	648	2,240,000	1771.34
1996	818	680	2,240,000	1771.34
1997	885.2	721	2,240,000	1781.88
1998	887.2	734	2,323,000	1781.88
1999		708	2,356,000	1781.88
2000		724	2,402,000	1781.88
2001		760	2,462,000	1808.54
2002		786	2,462,000	1843.26
2003	1137.1	830	2,462,000	1845.12
2004		884	2,682,000	2081.96
2005	1149.5	983	2,705,000	2081.96

Variable estimates

Time	Kenya pump price (KSh/L)	World oil price ($/barrel)	Conversion to Kenya pump price
1995	30.1	16.05	1.88
1996		18.12	
1997		23.07	
1998	37.8	14.97	2.53
1999		9.96	
2000	42	32.58	1.29
2001		27.92	
2002	39.2	27.41	1.43
2003		31.47	
2004		40.49	
2005			
2006			
2007	85		
		Estimate =	1.78

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