

Rural Energy Modeling

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Rural Energy Modeling

Mark Howells, Thomas Alfstad, Nicola Cross, Lindsey Jeftha & Gary Goldstein¹

0. Introduction

This paper presents the details and results of an energy model of a non-electrified rural village. The model itself was developed with MARKAL/TIMES, a modeling and optimization tool. Much of the data used in the model is based on data obtained from surveys and electricity loggers, while some is based on the authors' own assumptions (e.g. the number of households in the village).

In this context three themes are developed in this paper:

- Energy modeling tools in general and their application.
- Limitations experienced in terms of modeling rural settlements.
- The specific model developed for this paper.

The primary objective of the modeling process, in the approach taken, is to ascertain the least-cost method of meeting the energy needs of the village, under various constraints and user- defined bounds.

The model represents a hypothetical, but not untypical, South African rural village. For the model to obtain useful results, the data entered by the user needs to be as realistic as possible. While the energy patterns of urban (especially electrified) areas are well-documented, there is comparatively little data available for rural areas; what is available is general in nature and not useful in terms of what is needed for energy modeling purposes. This lack of data was the main obstacle throughout the modeling process.

Despite this lack of information, there are a number of issues concerning rural areas on which the authors are clear. The main thermal energy need of rural villagers is fuel for cooking, and space heating depending on location. Wood and biomass are important fuels,

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and subject to availability, coal, paraffin and, to a lesser extent in South Africa, LPG can also be an important fuel in rural areas. Accessibility and cost play an important role when determining fuel use. The collection of biomass-fuel (including wood and dung) has little monetary cost associated with its collection (although it can be very costly in terms of person-hours). In the context of poverty this is an important consideration. [Afrane Okese, 1998]

Most rural villagers have a low and sporadic income. This poses two problems for many rural villagers [Williams, 1994]:

(i) It limits their fuel options:

The inhabitants are only able to buy only small amounts of fuel when money is available to do so. This means that paraffin is a more viable fuel than LPG because it is possible to buy it in small amounts (an effect which is difficult to model using the approach adopted in this paper). It also implies that the cheapest fuel is often bought, regardless of the harmful health effects it may have.

(ii) There is limited expendable income to buy appliances:

Energy using appliances often require significant capital outlay relative to the household income. Thus, even if electricity were to become available, most households may not be able to use their electricity because of a lack of electrical appliances.

Compared to wealthier, electrified households, low income (mainly rural but also many urban) households suffer high levels of harmful emissions from local fuel use. Although emissions are released when coal is burnt in power stations, these are dispersed into the atmosphere through very tall stacks so that their concentration drops to low levels before it reaches people. By contrast the emissions from burning wood and coal in households are highly concentrated and slow moving. Electricity is therefore considered a clean fuel for households.

Most low income households in South Africa, burn fuels within or near, the household to meet their energy needs. Chimneys are not a common feature in Southern African rural houses and the residents are thus directly exposed to emissions and their damaging health effects. The second highest cause of infant mortality in South Africa is respiratory disease, of which the major cause is indoor air pollution from fuel burning [Eberhard & van Hooren, 1995]. The use of fuels such as paraffin and candles in the household can also be the cause of accidents that result in injury or death [Lloyd, 2002]. These social costs (not included in direct financial transactions) of fuels are a major concern of energy planners. The model in this project looks at the effects of placing costs (known as externality costs) on emissions in an attempt to show the 'social expense' of not using cleaner fuels such as electricity.

The paper presents the details of the modeling project by first focusing on integrated energy-environment-economic models in general and the limitations of these models. It then goes on to describe the limitations associated with rural energy modeling. Finally, it focuses on the model structure itself and the results obtained.

1. Integrated Energy-Environment-Economic Modeling

The purpose of integrated energy modeling is to inform debate and decision makers in a coherent manner and to develop insights into energy systems for reasons such as marketing services. It is important to set the broad scene in terms of such modeling. The intention of this work is development and therefore there is an emphasis on policy support. Available techniques generally fall into four broad categories – ranging from economy-wide top-down models to disaggregated detailed ‘bottom-up models’ [Harnisch et al 2002].

(a) The General Equilibrium Model

This model has a strong theoretical basis of market equilibria, and adopts a micro-economic view of consumer and producer behavior. The production function used and the supported elasticities play a well-defined role in determining the results obtained. The empirical foundation however is weak, and it is often questionable whether the scenarios captured are realistically represented. This type of model focuses on macro-economic research questions of national, multi-national and global significance.

(b) The Input-Output Model

This model is based on macro-economic interaction matrices, energy balances and labor market statistics. Activities are explained against the backdrop of sectoral development, energy carrier consumption and emissions development. It is difficult to incorporate changing conditions into models of this type, especially if the simulation period is over a long term. This type of model focuses on the formulation of macro-economic and sectoral research questions.

(c) The Optimization Model

This model uses technology databases containing detailed information on the intended area of application and the relevant cost aspects involved. Although these models are flexible, a high level of detail often needs to be incorporated into the model for the simulation to be realistic. This requires information such as load curves and technological requirement profiles, which are not always easy to acquire. Models of this nature usually implement a form of linear programming, and try to find an optimal solution subject to a collection of constraints. These models are usually applied when considering technology-related economic research questions.

(d) The Simulation Model

Like optimization models, these models, use detailed information pertaining to the area of application and cost aspects. Such a model, however, allows the user to explore different hypotheses via scenarios, and typically capture the area of interest at a macro-economic level. These models are used to investigate technologically-oriented measures where macro-economic interactions and price effects are less important.

1.1 Factors to Consider

Some aspects to consider when building a model are:

- Time and cost of development
- Modularity and transparency of structure
- Level of complexity involved
- Adaptability to new tasks
- Ability to analyze different types of cost (investor, social, consumer)
- Ability to model non-economic instruments
- Level of technological detail
- Accuracy of representation of non-CO₂ greenhouse gases
- Currency and accuracy of information (cost and performance)

It is in this context that the tools chosen for this exercise were selected. The first was a simulation model and the latter, an optimization model.

1.1.1 Models selected for this exercise

Firstly, in order to organize the data to be used, a simulation model, **LEAP**², was compiled. This allowed for transparent arrangement of the data. The tool is flexible, and so various possible scenarios and energy system configurations could be developed. This class of tool is also useful for developing an understanding of the planning possible with the data at hand. It also allows assumptions to disaggregate this data to be clearly presented. This is useful in a developing country context where data is not readily available.

Secondly, **MARKAL/TIMES** was the primary modeling tool used in this project. It is predominantly an optimization model, although it embeds certain characteristics of the input-output model as well as the simulation model. It builds directly onto a simulation model and was benchmarked against it. **MARKAL/TIMES** can also take a macro-economic view of the area under consideration, and perform its optimization relative to the costs incurred. Constraints were used to bound the model.

² Long Range Energy Alternatives Planning model developed by the Stockholm Environmental Institute.

The MARKAL/TIMES system is relatively expensive for developing-country users but it is flexible in terms of the detail and type of energy use system that can be modeled³.

Table 1 below summarises characteristics of different energy modeling approaches.

2. Common Limitations in Low-Income Rural Energy Modeling

Modeling low-income rural households poses challenges and limitations, among these, the structuring of the model, energy data limitations, and the hidden or ‘external’ costs associated with the energy system.

2.1 Modeling, objectives and behavior

There are two issues which pose particular challenges to modeling rural low income energy systems. The first relates to energy use and the devices employed by consumers, and the other relates to the rationale or behavior of consumers and linked to this the objectives of the modeling.

2.2 Device use modeling

When modeling for low-income households, a common mistake is to over-estimate the market penetration of electric appliances and hence electricity consumption [McFadzean, 2002]. Past experience shows that electricity is mainly used for lighting when first introduced to low income areas. [Eberhard & van Hooren, 1995] Households often still prefer traditional fuels and technologies for energy intensive activities like cooking and space heating, while consuming low volumes of electricity. Households can therefore remain in a state of ‘transition’ between traditional and modern fuels. This is something previous modeling studies has failed to capture.

³ For purchase of the various software components can be in the area of ten thousand \$US, plus training costs.

Table 1: Energy Model Characteristics

	GENERAL EQUILIBRIUM MODELS	INPUT-OUTPUT MODELS	OPTIMISATION MODELS	SIMULATION MODELS
Timeframe	Medium to Long Term	Short to Medium Term	Short to Long Term	Short to Long Term
Focus	Microeconomic	Macroeconomic	Technological energy systems with cost structures	Technological systems with specific general conditions and barriers
Calibration	Usually one reference year	Usually many years	One reference year	One reference year
Critical Factors	Nesting structure, elasticities	Quality of the historical time series, dynamics	Additional conditions (Bounds)	Quality of technical and economic analyses
Level of Detail of the Energy Systems	Low	Low	High	Partially high
System Boundaries	Entire economy	Entire economy	Energy system	Energy system
Flexibility in terms of a sectoral question formulation	High	High	Limited	Low
Interaction and Feedback with the entire economy	Considered	Considered	Not implicit, only with coupling	Not considered
Classical Question Formulation	Macroeconomic effects of environmentally economic instruments	Sectoral effects on environmentally economic instruments	Cost-effectiveness analyses	Identification of priorities for a mix of technological measures
Price-Quantity-Relations	Implicit	Implicit	Considered	Only in part, not implicitly considered
Rationality and Market Balances	In principle assumed	Not relevant	Implicit for future decision-making	Independent
Development of Reference Scenarios	Endogenous	Dependent on level of endogenization, usually considered endogenous	Plausible expert assumptions	With considerable exogenous guidelines
Technology and Technological Development	For the most part, combined together to single or few technologies	Aggregated at the level of interacting structures	As separate technologies and explicit estimations of each future development	As separate technologies and explicit estimations of each future development
Model Generator			Mostly yes	Mostly no
Strengths	Closed theoretical structure	Broad empirical foundation, sectoral disaggregation of industrial sectors	Applicable to technical total systems technological detailed questions, flexible application possibilities	Also usable without targeted entities for optimization, applicable to technical total systems technological detailed questions
Weaknesses	Small empirical basis, often low level of sectoral differentiation	Statistical theoretical background, founded solely upon historical analyses, extensive model preparation and maintenance	Implicitly rational optimization decisions, strongly influenced by bounds	Economic influences underrepresented, based considerably on the quality of expert knowledge

	GENERAL EQUILIBRIUM MODELS	INPUT-OUTPUT MODELS	OPTIMISATION MODELS	SIMULATION MODELS
Theoretical Foundation	Neo-classical	Historical analyses of the macroeconomic interaction matrix	Optimization with regard to technological-economic criteria	Primarily technological determinism of energy systems
Implementation of the Modeling	Decisions corresponding to nesting and elasticities	Econometric estimation of the interconnections of the interlacing matrix	Technological database with optimization algorithms	Technological database, expert knowledge
Flexibility in terms of Technically Detailed Questions	Low	Low	High, dependent upon the level of detail of the technological database	High for limited complexity
Flexibility in terms of the Scope of Reference	Medium	Fundamentally possible, low for existing models	High	Possible
Dynamics	Model inherent	Implemented in different degrees	Explicit via specific technologies	Explicit via specific technologies
Modeling Supply and Production	Function of production with nesting and elasticities	Interlacing structure via modeling	Endogenous	Scenarios
Modeling Demand and Consumption	Demand elasticities	Endogenous, in part also exogenous	In part, exogenous via scenarios, in part connected to economic development	On the basis of scenarios, coming out of economic growth

The simplification is also often made that a demand device such as a wood oven, in a small rural house, is modeled to meet a single energy service demand such as cooking. In reality devices such as ovens are often used to provide several services meeting space- and water- heating requirements as well as cooking. This significantly reduces the cost incurred compared to the use of several electrical devices to meet each specified energy demand. Thus, because space heating is supplied whenever cooking is undertaken, the assumed requirement for space heating is often overestimated. In fact, the low thermodynamic efficiency of these traditional cooking technologies can sometimes lead to an overproduction of space heat. An important issue that needs to be captured in refining this approach is modeling, more accurately the degree to which cooking and heating times co-inside.

2.3 Objectives and behavior

While there may be important motivators to behavior and planning, they often have several aspects.

Behavioral aspects of energy usage by the poor are often not comprehensively captured by current means [Prasad 2002]. The modeling tools used in the analysis are generally required to produce results that support or refute policy or investment decisions and not to predict the future. However, the latter is implicit in the former as, in order to contextualize these decisions, one assumes that future trends have been reasonably described. In order to do this, attention needs to be given to behavioral drivers, including:

- Cost
- Status
- Convenience
- Health
- Other welfare

In the modeling approach adopted in this paper, cost minimization is considered to be the objective function. While this is important in the context of poverty alleviation, it is limited in terms of choosing between options with similar costs.

Elasticity of energy service demand is an area that merits further investigation. Little work appears to have been done to establish the price elasticity/energy service demand relationships, other than those for individual fuels such as electricity [Gaunt 2002] for low income rural towns. Further studies on the income elasticity of energy consumption for low income households is essential if this issue is to be analyzed in a satisfactory manner. .

In terms of planning and policy, it may be useful to solve for more than one objective. For example, one may want to weight energy emissions reduction explicitly, as

opposed to including it implicitly in the costs. An example would be to optimize both for reduction of greenhouse gas emissions, local air pollution and energy system costs. Currently work is underway to develop a formulation of MARKAL which allows for the solving for multiple objectives.

2.4 Energy data limitations, emphasis and surveys

Energy and related data are essential both to quantify the object of the modeling and to propose and simulate solutions and their effects. Of interest is the availability of appropriate data, much of which is gathered through surveys carried out in rural areas. A subset of this important data is the costing of hidden or ‘externality’ costs. Another factor is a proposed “bounce” of increased demand if more energy suddenly becomes available.

2.4.1 Data collection

The availability of energy data such as usage profiles and appliance penetration coefficients for rural households is limited. This is in partly due to the methods used for data collection and the purpose of the investigation for which the data is being collected. Generally data is collected via surveys, though some logging of electricity consumption in low-income rural areas has been done [Dekeneh, 2002]. Specific weaknesses encountered during the surveys examined include the following:

- Lack of cooking, space- and water-heating activity data, including time-of-use and fuel consumption per task.
- Surveys that included useful data for energy system modeling often encompassed several areas of analysis, and did not have sufficient detail on energy related matters.
- Lack of parameters to be used to estimate fuel transport costs, which affects the users fuel cost.
- No data on hire purchase arrangements for energy-using devices.
- Energy modeling sometimes incorporates certain data to which results are very sensitive. This is often not established during preliminary modeling in order to guide the survey.

It should be borne in mind that several hundred data entries are necessary for relatively simple models. Therefore tailor made surveys for energy modeling activities needs to be undertaken, to improve on accuracy and to capture greater detail.

2.4.2 External costs of fuel use and non-commercial fuels

Models are often used to capture the environmental, health and welfare effects. These are often internalized in the modeling by using costs. These costs are normally not included in direct transactions and are referred to as external or externality costs. They may be given different weight in countries of different economic wealth. A year of life

lost to a person in a poor country because of pollution might be given a lower monetary value than a year of life lost in a rich country.

There are two types of externality cost often included in such modeling:

- Harmful health effects of energy use
- Cost of fuel collection.

Health costs are dependent on dose-response relationships between energy pollutants and health effects in terms of morbidity and mortality. Depending of the focus of the analysis, different costing for mortality and morbidity will be put into the model. Costs associated with fuel collection time are often not considered directly even when the time taken is significant.

3. Description of the Energy Model

A detailed energy systems model in the MARKAL/TIMES format was constructed of a hypothetical South African rural village.

3.1 Model Aims

The aims of the model were to:

- Develop an analysis tool for application in rural energy systems, with a flexible and wide range of possible configurations,
- Describe accurately energy use in rural households (in South Africa)
- Establish relationships and trends associated with sophisticated rural energy modeling,
- Expose weakness of this and other modeling approaches.

In order to do this a hypothetical village was modeled. Multiple fuel usages, as well as a variety of future supply options were chosen in order to illustrate potential that may develop by optimizing the model. The following characteristics of the village apply:

- The village was small with a steady growing population.
- Several fuels were used including wood, dung, coal, kerosene and LPG.
- Potential access to electricity (from a distributed generation grid, main grid or stand alone PV system) was available depending on the scenario run.
- Limited, but significant, resources of wood were available.

The development of the model included data collection, the use of a simulation modeling tool to develop energy demand forecasts and the development of a novel analysis in the MARKAL/TIMES cost optimization model.

3.2 Fuel and device data

Rural fuel usage estimates have been compiled in South Africa by aggregating data from surveys and compiling a composite picture [Trollip, 1994]. The shortcoming of this approach is that not all data sets are necessarily compatible. However, these were the only ones available.

Potential electrical device usage profiles and penetration data were obtained from low income rural households using statistical analysis and data logging. The technique is known as conditional demand analysis (CDA) and the load data can be extrapolated to communities with similar characteristics. A key finding of CDA is that the demand for electricity in low income households is related to the level of wealth and time electrified. Further research should investigate the relationship between demand and income elasticity.

Typical device data, such as efficiencies, lifetime, investment- and fuel-costs were taken from the relevant literature [Howells et al 2002, de Villiers & Matibe, 2000 and Jeftha 2002] and checked against field values from various sites or suppliers. Some of the energy demand devices considered were [Lloyd, 2002]:

	Fuel used	Demand met ⁴					
Technology		CKG	SHT	WHT	LGT	REF	OTH
Electricity supply technologies							
Diesel generator	Diesel	-	-	-	-	-	-
Gas generator	LPG	-	-	-	-	-	-
Grid connection	Electricity	-	-	-	-	-	-
Photovoltaic generator	Solar	-	-	-	-	-	-
HAWT	Wind	-	-	-	-	-	-
Electricity storage technologies							
Pumped storage	Electricity	-	-	-	-	-	-
Battery	Electricity	-	-	-	-	-	-
Demand devices							
Biomass open fire	Dung	X	X	X	-	-	-
Coal brazier	Coal	X	X	X	-	-	-
Coal stove	Coal	X	X	X	-	-	-
Wood open fire	Wood	X	X	X	-	-	-
Wood stove	Wood	X	X	X	-	-	-
Electric hot plate	Electricity	X	-	X	-	-	-
Electric stove	Electricity	X	-	X	-	-	-
LPG ring	LPG	X	-	X	-	-	-
Paraffin primus	Paraffin	X	-	X	-	-	-
Paraffin wick stove	Paraffin	X	-	X	-	-	-
Microwave	Electricity	X	-	-	-	-	-
Electric geyser	Electricity	-	-	X	-	-	-
LPG geyser	LPG	-	-	X	-	-	-
Paraffin geyser	Paraffin	-	-	X	-	-	-

⁴ Cooking (CKG), Space heating (SHT), Water heating (WHT), Lighting (LGT), Refrigeration (REF), Other (OTH).

Electric heater	Electricity	-	X	-	-	-	-
LPG heater	LPG	-	X	-	-	-	-
Paraffin heater	Paraffin	-	X	-	-	-	-
Incandescent lighting	Electricity	-	-	-	X	-	-
CFL lighting	Electricity	-	-	-	X	-	-
Candles	Candle wax	-	-	-	X	-	-
Paraffin press.	Paraffin	-	-	-	X	-	-
Paraffin wick	Paraffin	-	-	-	X	-	-
Electric fridge	Electricity	-	-	-	-	X	-
LPG fridge	LPG	-	-	-	-	X	-
Other devices (TV, radio etc.)		-	-	-	-	-	X

Based on aggregated, typical and specific data from case studies [de Villiers & Matimbe 2000], a model of the energy system of a hypothetical low-income rural village was constructed. The model was for a non-electrified low-income village with limited access to wind and micro-hydro resources. Cases of electricity supply included the following.

- (i) No access to electricity
- (ii) Mini-grid powered by distributed generation technologies
- (iii) Grid connection
- (iv) Stand-alone photovoltaic household-based systems.

Other runs included sensitivities on:

- Externality costs on emissions (which were modeled by using the tax parameters on MARKAL)
- The potential for increasing electricity consumption during off peak periods⁵

3.3 Method of model development

Key aims of the model development were to overcome shortcomings of existing models and establish relationships, which were important to fuel and technology ‘transitions’.

The initial data set and model structure were taken from a simulation model based on the Integrated Energy Planning Process of South Africa [Howells et al. 2002]. This model based the fineness of its detail on the data available. It was used to relate energy service demands to a range of technologies on a national level. End-use devices were employed to meet single demands only, a shortcoming that negates the use of a single device to meet several demands. In order to overcome these shortcomings, the device was restructured so that more than one demand could be met by it if feasible, with different

⁵ If this can be encouraged, larger volumes of electricity sales may improve the potential business case for electrification.

efficiencies from the same device. Attention was also given to the fact that certain energy services such as space heating would be met inadvertently through attempting to meet other demands.

Hourly load curve data was derived at appliance level using CDA, described in the appendix. This was then used to estimate energy service demand curves for the activities modeled. From this MARKAL/TIMES constructs (though limited by time slice resolution) a demand load curve.

3.4 Description of the MARKAL/TIMES Model

3.4.1 General description of model structure

The model structure is designed to resemble the energy system of rural African communities. It is to be used as a template in which the data collected from a particular village can be specified. The model will generate a solution identifying least-cost energy supply options, under user-defined constraints.

The useful energy demand has been divided into 6 end-use demand categories.

- Cooking,
- Space Heating,
- Water Heating,
- Lighting,
- Refrigeration
- Other (Radios, TVs, fans etc.).

These demands are met by a set of demand technologies, each meeting one or more of these useful energy demands. The supply of fuel for these technologies comes directly from the source in the case of renewable energy (solar, biomass and wood), from conversion technologies (locally generated electricity) or from imports to the village (grid electricity, LPG, paraffin and coal).

The model was set up to calculate emissions using emission factor data sets [Howells & de Villiers, 1998]. The following emissions related to energy supply and consumption, are calculated for all runs (see Appendix 1):

- Carbon Dioxide,
- Carbon Monoxide,
- Methane,
- Nitrous Oxide,
- Non-Methane Volatile Organic Compounds,
- Particulates,

- Particles smaller than 10 microns,
- And Sulfur Dioxide.

Figure 1 below, is the reference energy system for the village, illustrating the flow of energy carriers through the energy system depicted in the model. This shows how various technologies and fuels are configured to meet a projected energy demand.

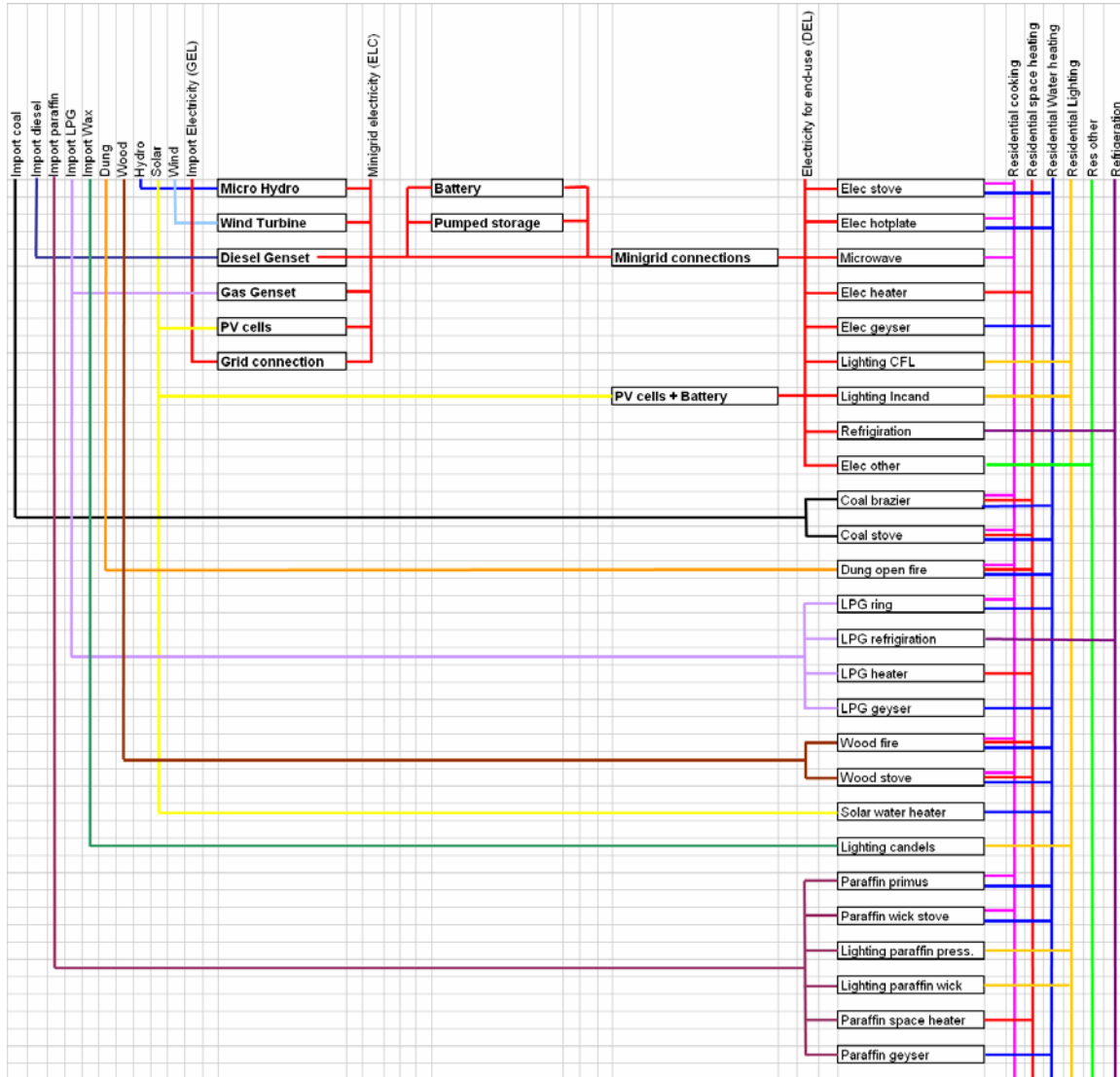


Figure 1. Reference Energy System of the Model

3.4.2 Special aspects of the model

Certain aspects of the rural energy systems described in previous sections require special attention when modeling in MARKAL/TIMES. New thinking on these matters is needed in order to improve on the shortcomings of previous modeling work.

One of the critical issues is the question of connection to the main grid. The ability to establish when and under what conditions a connection would be economically viable is one of the main conclusions sought. The supply of electricity to the end-use devices can be provided in three different ways: main grid connection, local generation feeding a mini-grid and small PV-cells supplying individual households. In order to simulate which of these supply options is available, it is necessary to distinguish between the electricity from the different sources. This is done by giving them different names and having interconnections linking one to the other.

Electricity can be imported from the grid if a grid connection is made available. Electricity imports have been segregated into 6 time slices in MARKAL/TIMES to allow electricity prices to be dependent on season of the year and time of day. The imported transmission grid electricity (GEL) is converted into electricity on the local mini-grid (ELC) by an interconnection technology. An investment cost is levied on this technology in order to capture the cost of building the grid connection. This separates the two, making grid electricity unavailable when there is no investment in a grid connection.

Regardless of whether there is a connection to the main-grid or not, electricity could be supplied to the local mini-grid through different distributed generation technologies. The conversion technologies made available were:

- Diesel Generators
- Gas Generators
- Wind Turbines
- Micro-hydro
- PV-cells

There are also possibilities for storage in batteries or pumped storage. These technologies all output ELC-electricity which, as mentioned above, is the electricity on the local grid. The cost of constructing this grid is captured as an investment cost for the energy carrier.

There is also a need to separate the electricity on the local grid from the electricity consumed by demand technologies. They can still be supplied with electricity through stand alone PV-cell units, even if there is no connection to the mini-grid. This is achieved by creating a demand-feeding electricity (DEL), that is the input energy carrier for all

electricity-consuming end-use devices. DEL can either be supplied by an interconnection technology, linking individual households to the local grid by converting ELC to DEL, or by direct supply from PV-cells. These PV-cells are a separate technology from those used to supply electricity for the local grid.

The next important issue concerns the problems related to technologies that meet more than one demand. A coal brazier, for instance, serves as a source for cooking, space- and water- heating. The output splits for these should not be fixed, however, given that the user has a measure of flexibility as to how the technology in question is to be used. To attain this flexibility a two stage dummy process with the same structure as a refinery (flexible energy outputs) has been introduced. In Figure 2 below a coal brazier is used as an example for illustration purposes.

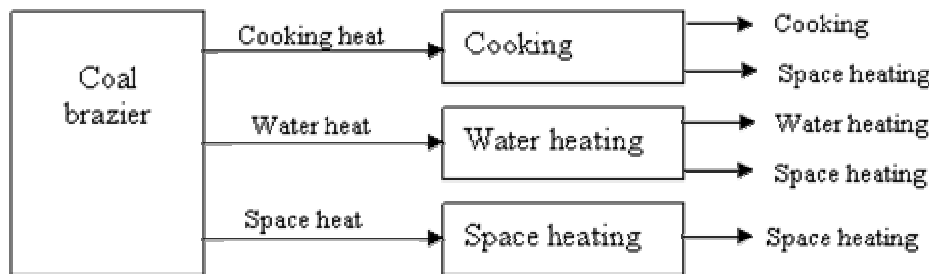


Figure 2: Demand Device Structure

The first stage of the structure shown above should be seen as the device itself. It has been characterized as a process technology. Costs and capacities are entered, along with a set of outputs corresponding to the possible uses of the brazier. Process technologies transform one energy carrier to another. Here the input fuel, coal, is transformed into heat.

In order to introduce the suppleness mentioned above, a characterization normally used for refineries with flexible outputs was applied. This allows for the specification of a maximum contribution from each output and as well as an overall maximum. The outputs are energy carriers representing heat that is used for the different activities (cooking, water and space heating); it is not cooking, water or space heating itself. Hence the top left arrow in the figure represents energy used for cooking. Some of this energy will eventually meet the cooking demand but the rest (heat loss) will be considered as space heating. The second set of boxes represents the actual end-use activity. The efficiency of the particular use and its outputs are also modeled here. These outputs, unlike the outputs

of the process technology, are fixed. In other words, if cooking takes place, space heating (according to ratios specified in the top right hand process box) will be produced.

4. Base Case Results

See Appendix 1 and 2 for selected results.

In the base scenario, the model was given the option of using all technologies. The optimal solution is then simply the least expensive mix of demand and supply technologies. However, constraints were imposed on the market penetration of new technologies and on the availability of fuel wood and biomass (dung). Base case model runs showed that traditional fuels are still the cheapest supply option for cooking, space- and water-heating. These fuels will not be displaced by the introduction of electricity. Coal also maintains a dominant role. Electricity was used mainly for lighting, refrigeration and other appliances such as TVs and radios. It consequently displaced paraffin and LPG for these purposes. These findings are in agreement with observations made in studies of newly electrified households [Eberhard and van Horen 1995]. Studies undertaken at the ISEP office, Eskom, emphasize that electricity consumption in low income households with recent grid connection has failed to reach the predicted consumption levels, which agrees with this finding.

Other scenarios were also developed to explore the dynamics of the energy system. When the grid option was disabled, distributed generation producing electricity for lighting, refrigeration and other requirements was preferred to the use of fossil fuels for these purposes. Micro-hydro was the cheapest alternative, although investment costs will vary with site. Diesel generators were the favored alternative when hydro-power was unavailable. Wind turbines, gas generators and photovoltaic cells are not price competitive and hence, no investment in these technologies was made.

In one scenario, externality costs were incorporated, thus attributing a price to emissions. The costs entered [Howells and de Villiers 1995] increased the price of the use of coal relative to that of electricity, causing the replacement of the former by the latter. This fuel switch reduces emission levels to about a third of the levels observed in the base case.

Cooking demand was met by a specified range of appliances in the first year. LPG rings and paraffin primus and wick stoves were then quickly phased out over the next few years due to their high fuel and investment costs compared to those of electric hot plates. Biomass is the cheapest option of all and was utilized to the maximum allowed by resource availability throughout the period. Fuel wood was also exploited to the limits permitted by resource constraints. The existing installed base of wood and coal stoves was also used to the maximum, but there was no investment in new capacity due to the high cost of these appliances. The relative contribution of these devices decreased as the demand increased,

while existing capacity declined as the units reached the end of their lifetimes. Available fuel wood resources not consumed in stoves were used in open wood fires. The remaining cooking demand was fulfilled by electric hotplates and coal braziers, both of which have a low investment and fuel cost. Later in the period investments in electric stoves were also made.

Water heating demand was met by the same multi-purpose technologies as for cooking demand. No investment in appliances designed exclusively for water heating, such as geysers, was made. In the case of cooking, for example, the total cooking demand was less than the sum of the energy produced by stoves and braziers; this is because part of their energy was also used for space heating and water heating. Coal braziers were the main contributor for water heating demand. Wood stoves and open fires also had a significant output, while electric hot plates contributed nothing towards the demand. It is also worth noting that there was a small investment in solar water-heaters during the second- and third- year. This capacity is used throughout the period but is not increased. The reason for this is that solar water-heaters ceased to be economical when electricity was introduced in the fourth year. It was still cheap (free) to use them, which explains why the installed capacity was not phased out.

Space heating demand was supplied primarily by waste heat from cooking and water heating activity. Little primary space heating activity was recorded. Coal was the major contributor to the demand, with modest supply from biomass, fuel wood and electricity with some variations between scenarios. There was a considerable overproduction of space heat due to the use of inefficient appliances. The use of solid fuels for cooking and water heating purposes, released more energy for space heat than for the intended purpose. With cooking demand being greater than that for space heating, this overproduction is inevitable. It is also a reasonable reflection of reality, as cooking gives off waste heat even when there is no need for space heating (warm summer day). One consequence of this is that space heating output does not rise steadily with demand as less waste heat will be produced when the technology shifts towards more efficient technologies.

CFL and incandescent lighting quickly displaced candles and paraffin lamps and would have contributed 100% to end-use demand within a couple of years had market penetration constraints not been specified. CFLs are the most economical option, but incandescent lights have a lower investment cost and might therefore be preferred by consumers. The difference in utility offered by the different alternatives was not incorporated in the model. Electric lighting will illuminate an entire room while candles and paraffin lamps are used mainly for task lighting and to help people find their way around the house. The introduction of electricity would therefore increase the demand for lighting (on an energy basis), while simultaneously increasing the utility for the households.

Refrigeration demand was configured to rise sharply after electrification, due to the accompanying reduction of cost of the service. Prior to electrification the demand was met by LPG which was then rapidly substituted with electricity. For appliances falling into the ‘other’ demand category the use of batteries as energy source was displaced by electricity after a few years.

4.1 Limitations of the approach taken

While based on hourly activity load data, MARKAL is limited to considering six ‘time-slices’ to describe a year of activity. The problems related to the inadequate time slice resolution was particularly evident when modeling space heat. MARKAL does time splits on a seasonal day/night basis, which implies that you specify a certain demand for say, a winter night. All demands specified for a winter night will then be evenly distributed over the time period. This will usually not be a good reflection of reality. Although it is reasonable to assume an even distribution of space heating demand, the cooking waste heat will be supplied over a fairly short period of time. So, even if total heat loss from cooking is greater than the demand for space heating (see previous section), the two are not matched in time. MARKAL is incapable of capturing this aspect. In reality cooking will greatly overproduce space heat over shorter time periods. This heat is lost to the surroundings and further space heating is needed (assuming it can be afforded). In a rural household the coal brazier (or other space heating appliance) used to cook supper would be left burning throughout the evening. The actual production of space heat (to meet space heat demand) would therefore be greater than the one predicted in MARKAL.

A significant weakness of the model structure, is the implicit assumption that energy service demand will be met, while dire poverty implies that needs are not being met.

Other weaknesses include the linear nature of the model. Bounds and outputs are thus limited to these shapes. Thus the model does not take into consideration that certain fuels and appliances can only be bought in significant volumes (e.g. LPG) involving high expenditure, perhaps with long periods of time between purchases. While this is not attractive to the rural poor, it may be to the model and the bias is not reflected in the optimization. [

A final weakness is the current inability of the models to solve for more than one objective function.⁶

⁶ Currently work is being undertaken to produce a variant of MARKAL that can be used for solving for multiple objectives, which could be well employed here.

5. Conclusions

Several important conclusions can be drawn from this work. These are separated into modeling results, modeling tool and data issues.

In terms of the modeling results:

- The model has successfully predicted low volumes of electricity consumption, which have been observed in households that have been electrified in South Africa. This result is based on a more appropriate approach to energy consumption in low-income areas, and is contrary to the forecasts of previous models.
- Because this analysis predicts that electricity consumption is likely to be low, there is potential to reduce the capacity of grid connection to low income areas and thus reduce costs.
- It is possible to identify technologies that have the potential to reduce peak demand while increasing the total volume of electricity sales to low income households.
- Externality costs are an important issue in terms of the effect on energy usage patterns,
- It is possible to define least cost pathways to meeting clearly defined goals, such as emissions limits.

Weaknesses of the modeling approach include the following:

- It is also possible to meet multiple objectives implicitly by weighting them in terms of cost. However, it is not possible to solve for multiple objectives simultaneously using the approach adopted.
- As the programming technique used is linear, it was not possible to model non-linear constraints and logic rules, which may apply to energy consumers who may be trying to maximize more than one objective.
- There is a clear bias away from expenditure with involves large installments of income in poor areas. This is not possible to model with linear programming. [However future work should look at developing appropriate technology specific discount rates.)

In terms of the knowledge base of rural energy use, there is little information available on the specific use of energy in households in terms of important modeling parameters including:

- Energy service elasticities
- Energy consumed per activity and the efficiency of consumption,
- The effect of other drivers such as convenience on energy demand,

Finally there is a clear mismatch between life-cycle economic energy systems costing data for quantitative modeling and many questionnaires used in surveys.

6. Recommendations and Next Steps

Following the work, it is clear that there is potential for significant inroads to be made in this field. Specifically, further investigation is needed with regard to further develop the modeling, data and collection methodology.

6.1 Modeling tools and approach improvement:

- The formal development of models (possibly MARKAL or TIMES) which:
 - solve for multiple objectives (both to help policy makers determine possible technical solutions to multiple political objectives, and to better describe the behavior of individuals.)
 - determine with algorithms the most important data in terms of the solutions sought, which will in turn inform the emphasis of data surveys in rural areas.
(Appendix 3)
- The integration of national models, demand side management issues, planned electricity load growth, renewable energy targets, distributed generation and grid connection should be done to investigate opportunities to accelerate development
- Improving the accessibility of education and support for modeling tools should be promoted if their benefits are to be realized.
- The development and application of non-linear tools, with easy-to-use interfaces, which may be developed for a standard rural energy survey or questionnaire.

Data improvement, and relationships are not well established for local conditions for use in the modeling. The following recommendations are suggested in order to derive energy-use relationships:

- Energy price elasticities should be analyzed to determine the relationship between the price of energy services and the demand for them. In particular emphasis should be placed on the derivation of income elasticity with useful energy service demand.
- Work should be undertaken to establish relationships between cultural preferences and their relationship to energy demand.
- An appropriate database system should be developed to determine and compare generic modeling values for socio-economic groupings.
- Externality cost ranges should be calculated for specific effects of indoor pollution, such as
 - health care costs, and
 - subjective values associated with mortality or morbidity in order to correctly model health effects.

Surveys are the primary method for collecting data from the field. This may be the only effective methodology in terms of cost and effectiveness. It is suggested that pointed surveys should be developed in order to inform energy modeling, specifically on:

- Timing and fuel use per activity,
- Appliance used per activity,
- Full transport costs associated with fuel purchases,
- Extent of fuel 're-sold' or used for non-energy purposes.

6.2 Final remarks

Following on from this work, the ERI has designed a questionnaire (Appendix 4) and targeted a test town to look at interventions that may be identified by the modeling to:

- Reduce system costs to alleviate poverty,
- Reduce local pollutants, and
- Reduce CO₂ emissions

This site will be used to test and develop new issues identified in this work.

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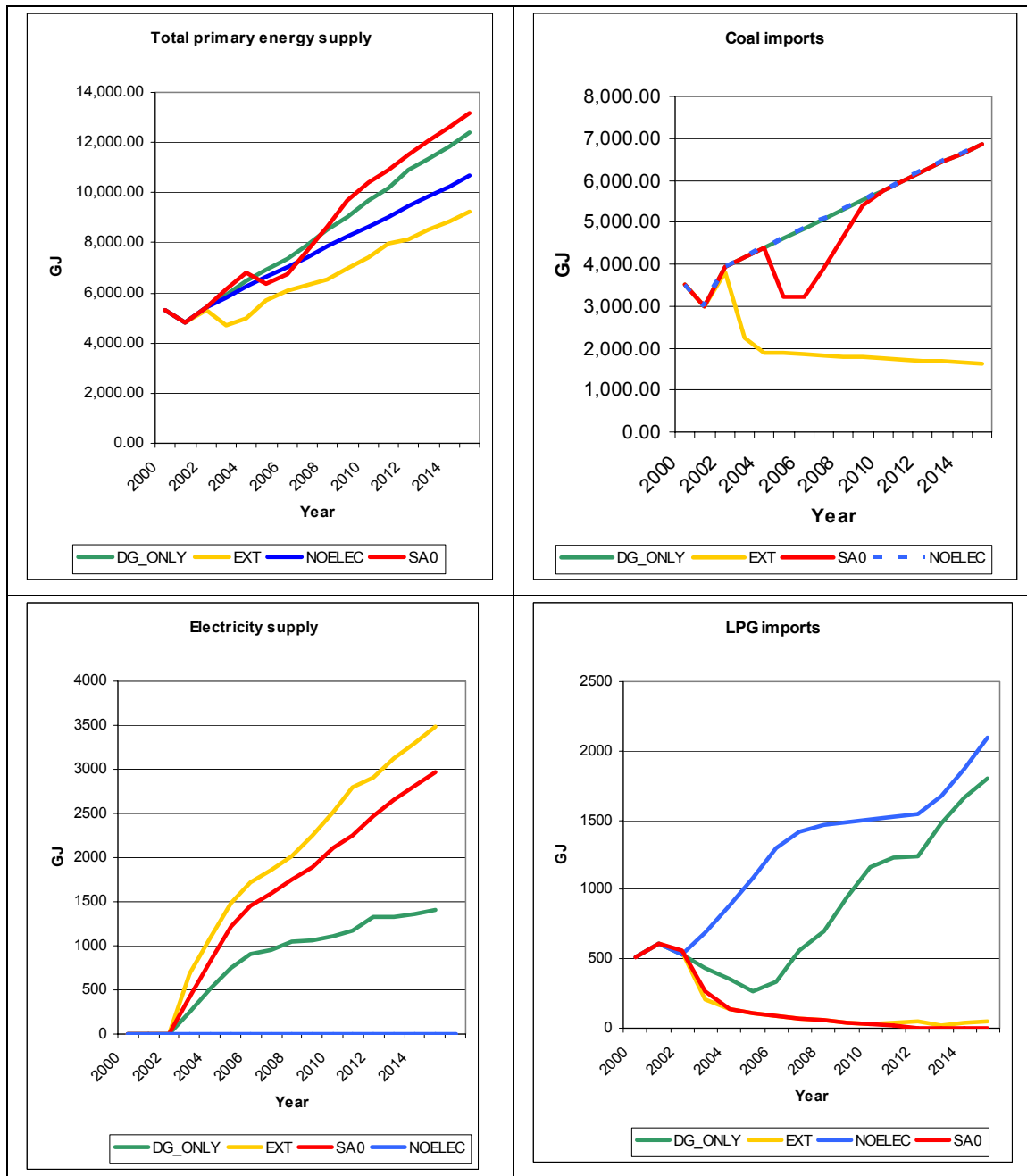
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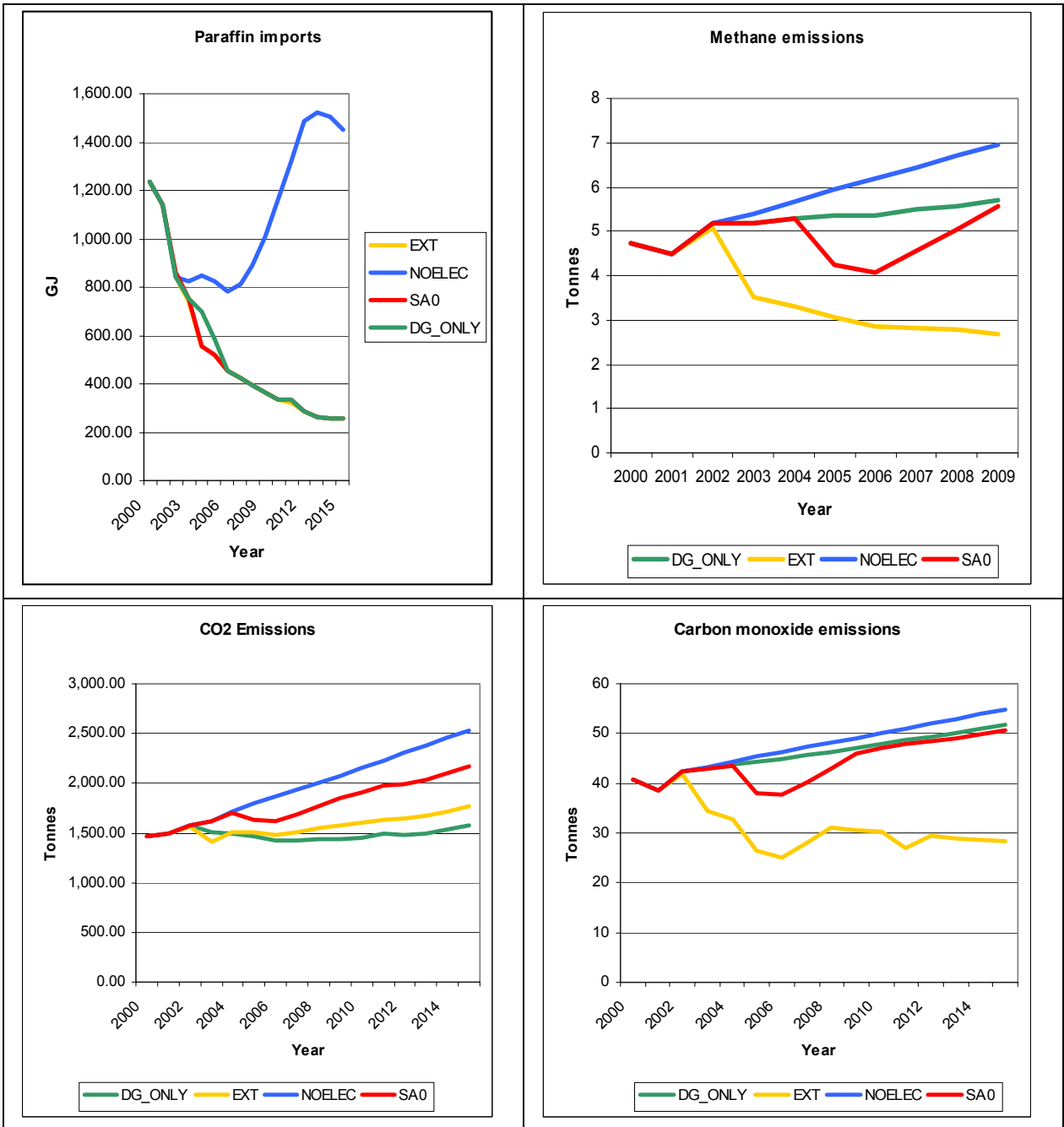
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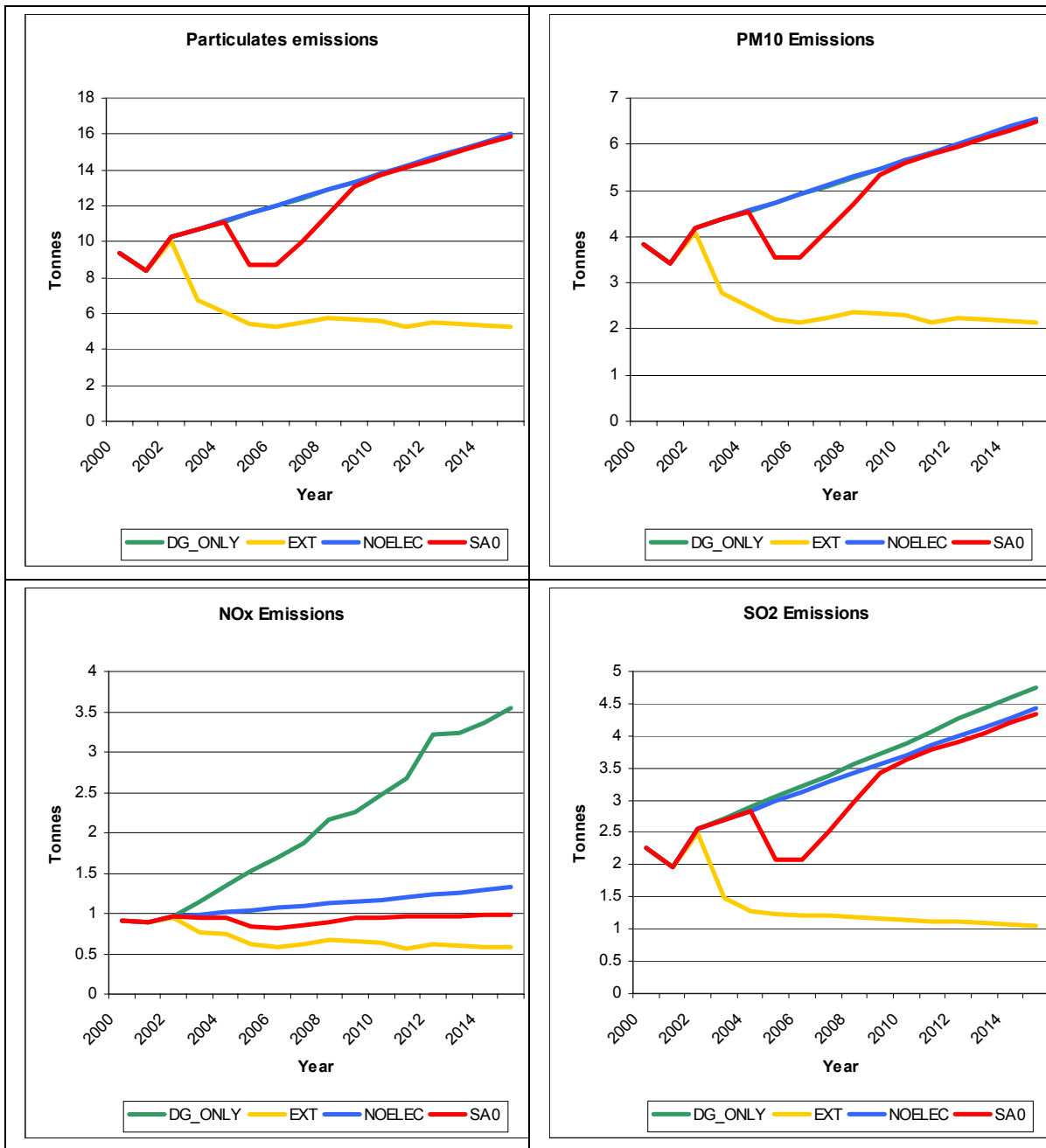
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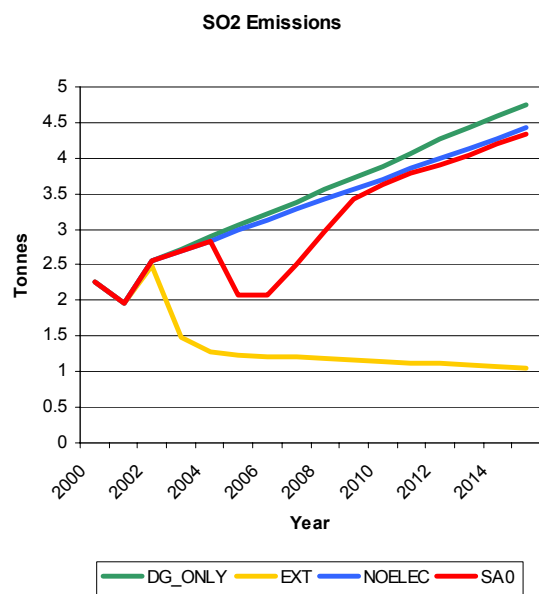
APPENDIX 1: Scenario Comparisons

- Base case scenario (SA0)
- Distributed generation only (DG_ONLY)
- No electricity generation or imports (NOELEC)
- Externalities (EXT)

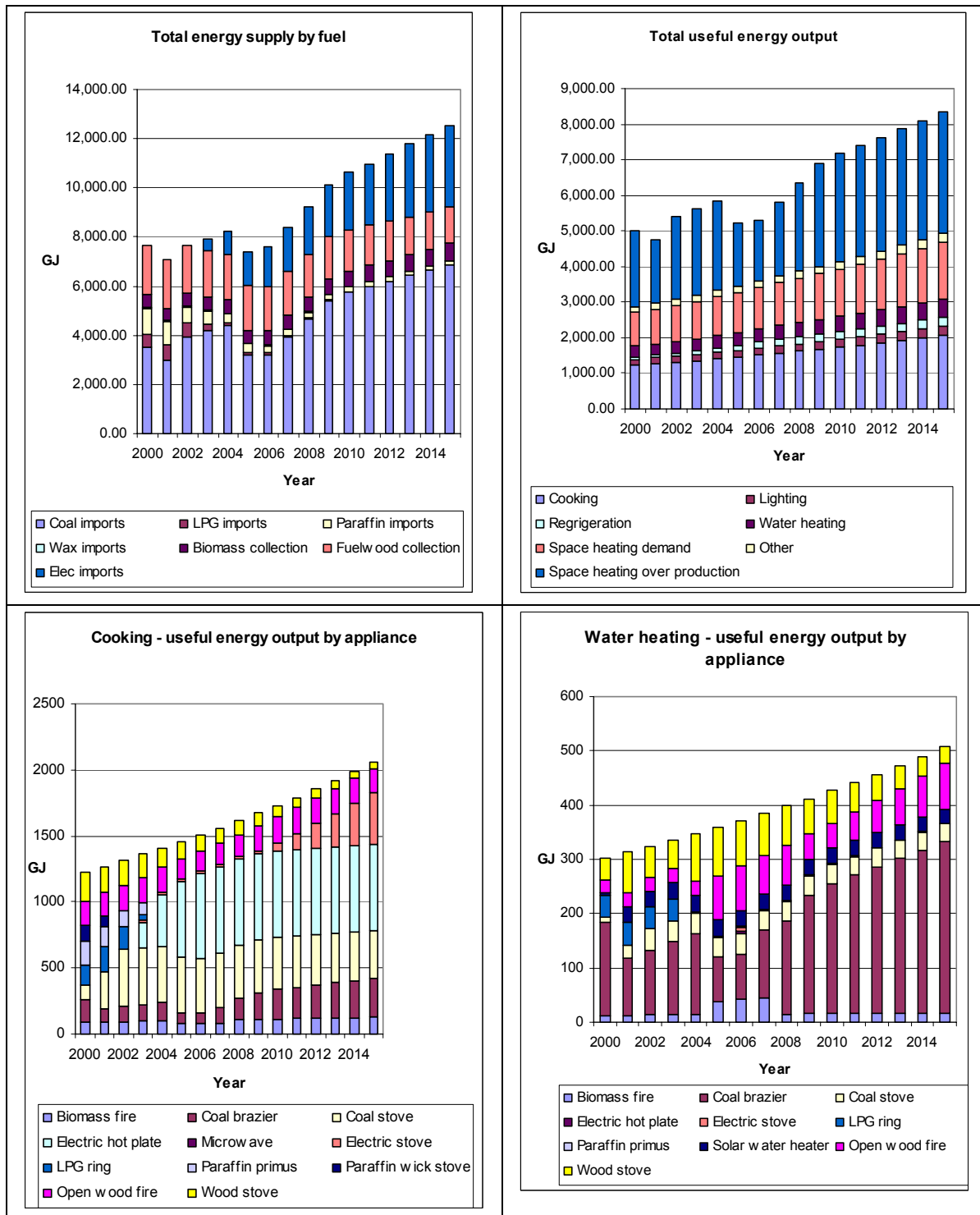


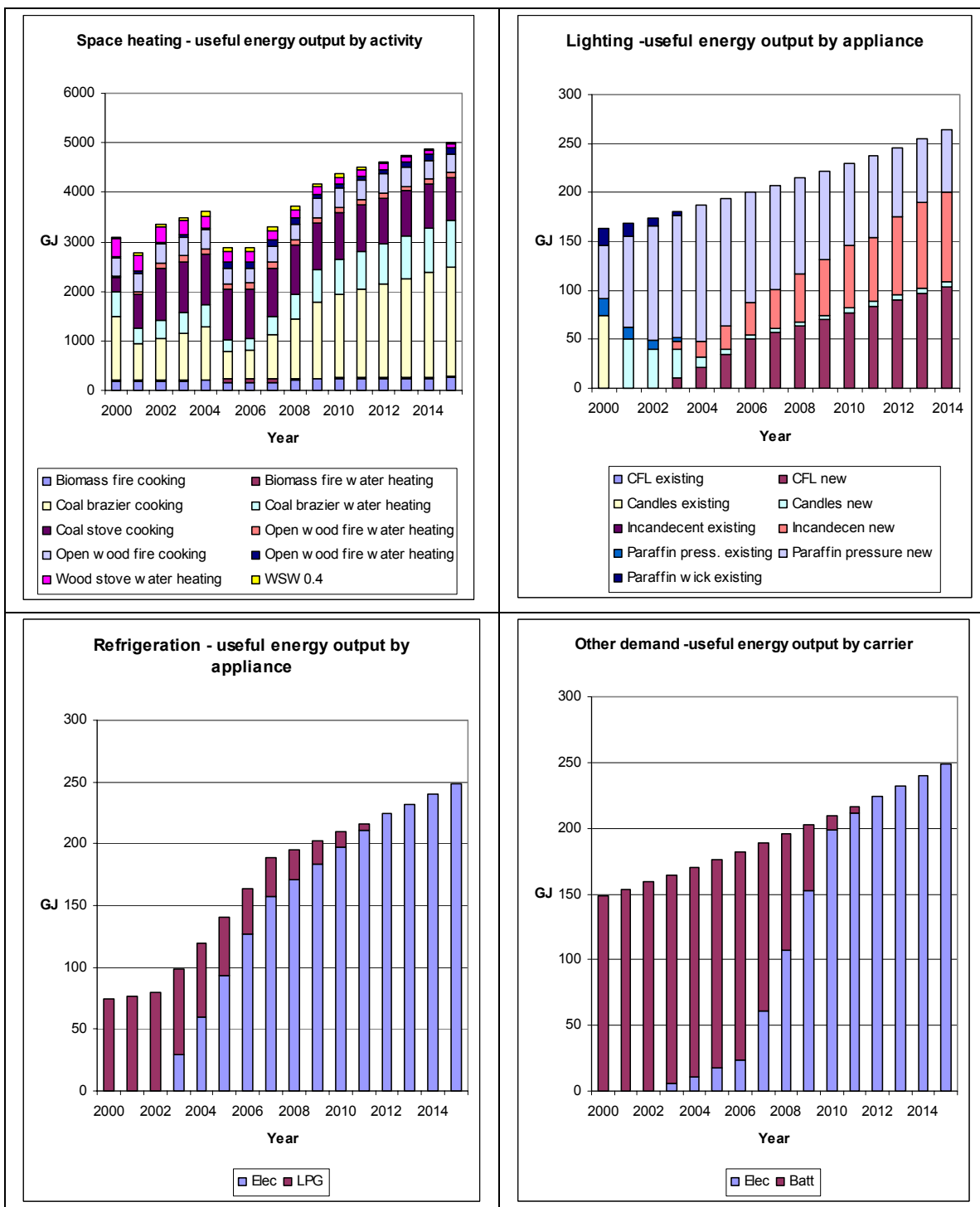






APPENDIX 2: Base Case Results





APPENDIX 3: Reduction in the Complexity of the Problem

In general, an optimization problem consists of

- a set of alternatives from which to choose, known as the **Decision Space**,
- a set of restrictions on the alternatives, known as **Constraints**, and
- a utility function which gives an measure of the fitness of a selected alternative

The size of the decision space influences the complexity of the optimization problem, and is determined by factors such as the **number of variables** to consider (the ‘*dimensionality*’ of the problem) and the **domain** of each of these variables. It is desirable to reduce the number of variables, not just to reduce the complexity of the problem, but also because it may be the case that certain of the variables have a greater effect on the utility than others.

Techniques such as sensitivity analysis have been used to determine those variables which affect the model outcome most significantly. However, in cases where the utility function involves co-dependence of variables or *epitasis*, this may not work. More recent techniques such as **Bucket Elimination** [1] can then be used not just to eliminate unnecessary variables but also redundant constraints from the problem.

A more important aspect of this form of analysis is the determination of decision or classification attributes. Suppose that we have found a set of suitable candidate solutions to the problem at hand. It is then possible to apply techniques such as decision-tree analysis, k- and c- means clustering, or rough set analysis [2] to the candidate set, and in so doing classify the candidates according to certain attributes. This could, for example, assist in the drafting of a suitable questionnaire that could be used to gather information for further study.

References

- [1] Dechter, R.J., *Bucket Elimination: A Unifying Framework for Reasoning*
- [2] Komorowski, J., Pawlak, Z., Polkowski, L., Skowron, A., *Rough Sets: A Tutori*

APPENDIX 4: Housing Energization

- Baseline Questionnaire -

Survey Questionnaire for Rural Households

Details of Interview

Date: _____

Name of Interviewer: _____

Household Information







Location of house: _____

Family name/identification: _____






Name: _____

Gender: ☐ Male  ☐ Female 

Person responsible for household (i.e. Head of Household):

☐ Father  ☐ Mother  ☐ Husband  ☐ Wife 
☐ Son  ☐ Daughter  ☐ Relative

Relationship to Head of Household:

☐ Head  ☐ Wife  ☐ Husband  ☐ Son 
☐ Daughter  ☐ Relative ☐ Unrelated

Number of occupants in the house: _____

Number of rooms in the house: _____

Energy Uses





The following questions deal with energy uses in and around the household.


Specifically, we are interested in **Cooking** , **Space Heating**    

Water Heating for Washing   and **Lighting**   







Cooking


Main Fuel:

- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
- ☐ Paraffin 
☐ Other: _____

Reason for use? 





Type of Appliance Used:

- ☐ Mbaula 
☐ LP GAS Cooker 
☐ Wick Stove 
- ☐ Primus Stove 
☐ Electric Stove 
- ☐ Wood/coal Stove 
☐ Other: _____

Reason for use? 


- ☐ Cheaper
 ☐ Already have it
 ☐ No Alternative
- ☐ Other: (explain) _____

Who makes the decision to use this fuel for this service?

- ☐ Male Head of House 
☐ Female Head of House 
- ☐ Daughter 
☐ Son 
☐ Other: _____





I like the fuel I use for this service

- ☐ Yes 
☐ No 

Reason for use? 

- ☐ Cheap
 ☐ Easily Available
 ☐ Easy to use
- ☐ Familiar Fuel
 ☐ Only Available Fuel
 ☐ Can't afford other fuels
- ☐ Fire starts easily
 ☐ No other appliances
 ☐ Smoky
- ☐ Dirty
 ☐ Unsafe
 ☐ Expensive
- ☐ Takes time to burn
 ☐ It is a traditional fuel
 ☐ Burns for long time
- ☐ Other Reason: _____
- ☐ More Comments: _____


Other energy sources used for this service:


- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
☐ Paraffin 
- ☐ Other (explain): _____

When do you prefer to use these alternatives?







Space Heating


Main Fuel:

- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
☐ Paraffin 
- ☐ Other: _____

Reason for use? 





Type of Appliance Used:

- ☐ Mbuala 
☐ LP GAS Heater 
☐ Wick Heater 
- ☐ Pressure Stove 
☐ Electric Heater 
- ☐ Coal/wood Stove 
☐ Other: _____

Reason for use? 


- ☐ Cheaper ☐ Already has it ☐ No Alternative
- ☐ Other: (explain) _____

Who makes the decision to use this fuel for this service?

- ☐ Male Head of House 
☐ Female Head of House 
- ☐ Daughter 
☐ Son 
☐ Other: _____





I like the fuel I use for this service

- ☐ Yes 
☐ No 

Reason? 

- ☐ Cheap ☐ Easily Available ☐ Easy to use
- ☐ Familiar Fuel ☐ Only Available Fuel ☐ Can't afford other fuels
- ☐ Fire starts easily ☐ No other appliances ☐ Smoky
- ☐ Dirty ☐ Unsafe ☐ Expensive
- ☐ Takes time to burn ☐ It is a traditional fuel ☐ Burns for long time
- ☐ Other Reason: _____
- ☐ More Comments: _____

Other energy sources used for this service:

- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
☐ Paraffin 
- ☐ Other (explain): _____


When do you prefer to use these alternatives?

Water Heating (for washing)

Main Fuel:

- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
☐ Paraffin 

☐ Other (explain): _____


Reason for use? 

- ☐ Mbula 
☐ LP Gas Cooker 
☐ Wick Stove 

Type of Appliance Used:

- ☐ Pressure Stove 
☐ Electric Stove 



- ☐ Coal/wood Stove 
☐ Other (explain): _____



Reason for use? 

- ☐ Cheaper ☐ Already has it ☐ No Alternative

☐ Other: (explain) _____


Who makes the decision to use this fuel for this service?

- ☐ Male Head of House 
☐ Female Head of House 

- ☐ Daughter 
☐ Son 
☐ Other: _____

I like the fuel I use for this service

- ☐ Yes 
☐ No 

Reason for use? 

- ☐ Cheap ☐ Easily Available ☐ Easy to use
☐ Familiar Fuel ☐ Only Available Fuel ☐ Can't afford other fuels
☐ Fire starts easily ☐ No other appliances ☐ Smoky
☐ Dirty ☐ Unsafe ☐ Expensive
☐ Takes time to burn ☐ It is a traditional fuel ☐ Burns for long time

☐ Other Reason: _____

☐ More Comments: _____

Other energy sources used for this service:







- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
☐ Paraffin 


☐ Other (explain): _____

When do you prefer to use these alternatives?






Lighting


Main Fuel:

- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
- ☐ Batteries 
☐ Paraffin 
☐ Candles 
- ☐ Other (explain): _____

Reason for use? 





Type of Appliance Used:

- ☐ LP Gas Light 
☐ Candles 
☐ Torch 
- ☐ Lantern 
☐ Electric Lighting 
- ☐ Other (explain): _____

Reason for use? 


- ☐ Cheaper ☐ Already has it ☐ No Alternative
- ☐ Other: (explain) _____

Who makes the decision to use this fuel for this service?

- ☐ Male Head of H/hold 
☐ Female Head of H/hold 
- ☐ Daughter 
☐ Son 
☐ Other: _____





I like the fuel I use for this service

- ☐ Yes 
☐ No 

Reason for use? 

- ☐ Cheap ☐ Easily Available ☐ Easy to use
- ☐ Familiar Fuel ☐ Only Available Fuel ☐ Can't afford other fuels
- ☐ Fire starts easily ☐ No other appliances ☐ Smoky
- ☐ Dirty ☐ Unsafe ☐ Expensive
- ☐ Takes time to burn ☐ It is a traditional fuel ☐ Burns for long time
- ☐ Other Reason: _____
- ☐ More Comments: _____












Other energy sources used for this service:

- ☐ LP Gas 
☐ Electricity 
☐ Firewood 
☐ Paraffin 
- ☐ Other (explain): _____








When do you prefer to use these alternatives?

Household Appliances

What are the main energy sources that you use for, task lighting, radio, TV, communication (i.e. cell phone charging) and other?

	Task Lighting 	Radio 	TV 	Communication 	Other (specify) _____
Electricity 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
LP Gas 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Paraffin 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Candles 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Torches 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Batteries 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Generator 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other (please specify) _____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

What sort of appliances do you have, or would you like to have?

Kettle 	<input type="checkbox"/> I have one	<input type="checkbox"/> I'd like to get one
Oven 	<input type="checkbox"/> I have one	<input type="checkbox"/> I'd like to get one
Toaster 	<input type="checkbox"/> I have one	<input type="checkbox"/> I'd like to get one
Refrigerator 	<input type="checkbox"/> I have one	<input type="checkbox"/> I'd like to get one
Freezer 	<input type="checkbox"/> I have one	<input type="checkbox"/> I'd like to get one
Radio 	<input type="checkbox"/> I have one	<input type="checkbox"/> I'd like to get one
Television 	<input type="checkbox"/> I have one	<input type="checkbox"/> I'd like to get one

Energy Uses

The household fuel usage is...

☐ More during winter (or on cold days) and less in summer



☐ The same in summer as in winter



We use _____

☐ Kgs 

☐ Bottles 

☐ Bags 

☐ Rands 

of fuel in winter

We use _____

☐ Kgs 

☐ Bottles 

☐ Bags 

☐ Rands 

of fuel in summer

Fuel Source and Usage

I buy all the fuel I use

☐ Yes



☐ No



I get some of my fuel for free

☐ Yes



☐ No



(If yes) I get _____

☐ Kgs 

☐ Bottles 

☐ Bags 

☐ Rands 

for free

Where do you get this free fuel?

Where do you buy your fuel?

☐ Someone delivers to my door

☐ I buy at a market or shop

☐ Other:

From how many different suppliers do you buy fuel?

☐ I always use the same supplier

☐ I buy from _____ different suppliers

How do you pay for the fuel?



☐ In cash each time I buy

☐ In cash at the end of the week

☐ In cash at the end of the month

☐ In advance at the start of the month

☐ By cheque or credit card, in advance

☐ By cheque or credit card at the end of the month

☐ In kind (exchange for something else)

☐ Other (specify):

What happens if you cannot pay for your fuel?

☐ Supplier gives credit

☐ Supplier gives a loan

☐ Obtain fuel from another supplier

☐ Borrow money from friends/relatives

☐ Borrow fuel from friends/relatives

☐ Other:

Why do you get the loan from the supplier and not from other sources?

☐ Dealer is a relative

☐ Supplier is a friend

☐ Other sources are more expensive

☐ It is easy

☐ There are no other sources here

What problems do you experience with the fuel?

☐ Dirty



☐ Takes time to burn



☐ Smoke



☐ Makes us sick



☐ Needs wood/paraffin to ignite

☐ Other

Are you aware of the health problems caused by the fuel?

☐ Yes



☐ No



If yes, which problems?

Has anyone in the household suffered from these health problems?

☐ Yes



☐ No




What do you do with any ash?

☐ Throw it away

☐ Build something

☐ Other

Hours per Activity

How many hours  a day do the following activities occur?

Winter



Summer



Cooking



Space Heating



Water Heating











Refrigeration



Other (please specify)

When do you normally perform each of the following activities?

					12-2 am	2-4 am	4-6 am	6-8 am	8-10 am	10-12 am	12-2 pm	2-4 pm	4-6 pm	6-8 pm	8-10 pm	10-12 pm
Cooking 	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Space Heating 	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Water Heating 	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Refrigeration 	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other (Radio, TV...) 	Summer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Winter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Electricity Supply

Is the household electrified?



☐ Yes



☐ No



If yes, for how long?

For what is the electricity used?

☐ Cooking



☐ Water Heating (Geyser)



☐ Space Heating



☐ Lighting



☐ Space Cooling



☐ Ironing



☐ Water Heating (Kettle)



☐ TV & Radio



Past Electricity Usage

This time last year, what was the household income?



R

What was your monthly fuel bill this time last year?



R

Did you spend the same amount on fuel last year as you do now?

☐ Yes



☐ No



Did you use the same fuels last year as you do now?

☐ Yes



☐ No



If not, which fuels did you use this time last year?

☐ Paraffin



☐ Dung



☐ Fuel Wood



☐ LP Gas





☐ Coal




☐ Other:

Household Income and Expenses

Occupations/Jobs of the Household Members:


Member Name	Occupation/Job	WEEKLY Income 	MONTHLY Income 
		R	R
		R	R
		R	R
		R	R
		R	R
		R	R

Do you get money from elsewhere? 

☐ Yes 
☐ No 

If yes: How often do you get this amount?

☐ At least once per month
☐ At least twice per year
☐ Other (explain) _____

Are there any other sources of income? 















(If yes, please specify the source and the amount)

Source: _____

Amount: R _____

Monthly Expenses

Which of the items below do you buy every month? Please specify the amounts spent as well.

Item	Amount
<input type="checkbox"/> Food 	R _____
<input type="checkbox"/> Clothes 	R _____
<input type="checkbox"/> Rent 	R _____
<input type="checkbox"/> Transport 	R _____
<input type="checkbox"/> School Fees 	R _____
<input type="checkbox"/> Entertainment 	R _____
<input type="checkbox"/> Servicing of Loans 	R _____
<input type="checkbox"/> Coal 	R _____
<input type="checkbox"/> Paraffin 	R _____
<input type="checkbox"/> Electricity 	R _____
<input type="checkbox"/> LP Gas 	R _____
<input type="checkbox"/> Dry-Cell Batteries 	R _____
<input type="checkbox"/> Lead-Acid Batteries 	R _____
<input type="checkbox"/> Fuel Wood 	R _____
<input type="checkbox"/> Other (please specify)	R _____
	R _____
	R _____
	R _____



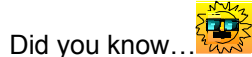
Did you know?



Did you know...
A cleaner burning (no smoke) fuel is better for your health and the health of your children?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
Solar electric (solar photo-voltaic) power is safe and easy to use?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
LP Gas is very safe and does not kill as many people as paraffin?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
Paraffin is responsible for approximately 4000 deaths each year in South Africa?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
Changing the fuel you use could save you money and time. E.g. changing from paraffin to LP Gas?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
The highest cause of death in South Africa is due to respiratory diseases caused by indoor pollution (i.e. from coal and wood fires made in Mbaulas)?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
You can light a fire in a way that reduces the smoke – it is called the 'Basa Magogo' method where the fire is lit on top and burns down instead of burning from the bottom up?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
Chopping away too much wood causes wood shortages?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
That you would save time if you could afford not having to collect wood – time which you could use productively by doing more of what you enjoy?

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**



Did you know...
Careful and thoughtful use of energy will save you money and time and will improve your quality of life.

☐ Yes **VOTE YES!**

☐ No **VOTE NO!**

APPENDIX 5: CDA – Conditional Demand Analysis

Definition

Conditional Demand Analysis (CDA) is a statistical method for disaggregating energy billing information along with household and behavior variables in order to develop units of energy consumption based on end use. CDA can be used by utility marketing staff to help develop marketing information for their customers on the average energy use by appliance type.

In the case of the MARKAL Rural Village Energy Model, specific load curve data was not available. Instead, the method of CDA was used to derive values for the load profiles, based on data captured via surveys or by monitoring electricity usage for many rural villages. When electrical data is logged - which implies that the data can be collected only from electrified villages - it can only provide overall, average load curves of a village. However, by applying mathematical algorithms it is possible to disaggregate the averaged load curves into several appliance profiles.

The algorithm requires the use of the *penetration level* of the specified village or population. This term refers to the proportion of the population that uses a specific appliance and it varies with income and time electrified. All of these factors need to be taken into consideration in order to obtain realistic penetration level values. Often, surveys show penetration levels at a specific time and income level, and these can be extrapolated by making assumptions with regard to income growth. Unfortunately, income growth in rural areas is extremely unpredictable.

The appliance profiles generated through CDA are based on differences in the appliance ownership of the consumers. The profiles generated in this way can be used as general curves for any community or population with similar characteristics as those analyzed. The main difficulty in using CDA curves to develop appliance profiles for a specific village lies in finding CDA curves that are appropriate to that village and then determining the penetration levels of each appliance type within the village.

The points on the CDA curve are coefficient values expressed in *amperes* (amps) and cannot be used as they are. To derive an applicable load curve for a given appliance, this coefficient must first be multiplied with the penetration level for that appliance within the specified village. The curve can then be expressed in more suitable units, such as kVA, by simple adjustment.

Although the CDA curves represent general averages that will never be entirely accurate, the values are very useful where data is unavailable. They are considered an adequate source of the load curve data used in the model derived in this project. Once appliance curves have been determined, they can be combined and used to develop the

total activity curves for a given activity such as cooking. These activity curves are used in the model to specify demand for the five main activities. The penetration levels are enforced in the model by using IBOND investment capacity limit parameters to control the level of use of electrical appliances should electrification occur.