An energy model for a low-income African village


Aims

- 2.5 million people die per annum due to the use of traditional fuels
- An appropriate method to:
  - Assimilate data
  - And with the use of TIMES model of ETSAP to:
    - Model multifunctional appliances
    - Describe timing of energy use
- Understand the economics of fuel transitions with respect to:
  - Grid and distributed electrification
  - Incorporating health effect
  - and climate change opportunities
Overview

- Introduction
- Rural energy use in Africa
- The modeling framework:
  - Inclusion of load curves
  - Single appliance multiple services and fuels
  - Inclusion of externality costs
  - Data collection issues addressed
- The case study Nkweletshe
- Scenarios
- Results
- Conclusions

Introduction

- Fuel-use transition is an important part of development
- Low income use is not well described statistically
- Dynamics are not well understood
  - Low income users make clever use of limitations
  - Planning efforts have been incorrect and overestimated the uptake of commercial fuels, such as electricity, effecting the economics of electrification
- Limited resource for developing countries mean that informed planning is essential in order to maximize the effect of development initiatives such as electrification
- In this context it is useful to help identify possible market opportunities which derive from and encourage development of the poor
Introduction

- New model of energy system dynamics using the TIMES framework of ETSAP
- Case study and ‘calibration’ using the village Nkweletsheni in South Africa
- Develop scenarios to examine:
  - Business as usual
  - Electrification economics
  - Potential effects of CDM
  - Improving quality of life

Rural energy use in Africa

- Internationally 2.4 billion people rely on biomass
- Biomass is Africa chief source of fuel household use
- Health and environmental effects are severe and there are therefore societal costs to be considered
- Incomes are low. In SA grid electrified households are often later ‘disconnected’
- Capital costs of appliances and fuels are prohibitive
- A range of fuels are used
- Appliances run on more than one fuel and meet more than one demand
- Previous crude representations have hampered planning
  - Models, data, macro data are unhelpful and limited
The Modeling Framework

- Previous work was with MARKAL with PESD at Stanford, and developed a data survey.
- TIMES is a bottom up, more flexible, high resolution multi-period least cost optimization framework.
- Driver, for this application, is the assumed demand for energy service – or useful energy demand for the following:
  - cooking (CKG); space heating (SHT); water heating (WHT);
  - lighting (LGT); refrigeration (REF), and other (radios, TVs, etc., OTH).
- Need to move away from simple accounting frameworks.
- The reference energy system ...
Inclusion of load curves

- Need to move to include load profile data not possible in the current MARKAL framework
- Account for time dependant phenomena
- Exceptionally important as economically only certain activities may be suitable for electricity use. This means different electricity supply investment patterns would be predicted to an average profile.
- Identification of potential appropriate DSM appliances e.g. off peak hybrid solar water heating
Inclusion of load curves

- Examine electrification potentials:
  - Load shifting via storage
  - And fuel switching during peak periods
- Should we electrify with DSM ‘built in’ to reduce system costs?
- Collected via survey data used as the default
- Through electrical monitoring and statistical “Conditional Demand Analysis” (CDA) of low income rural households used for electrical devices as shown…

Electricity consumption with the profile as given by CDA

Paraffin consumption with the same profile as in the survey

Electric stove - operation constrained to have the same activity profile as given by CDA

Dummy storage

Dummy variable - cooking heat - from electric appliances

Paraffin cooking

Useful cooking demand – with the profile from the survey
Multiple fuels, single appliance, multiple services

- Due to income constraints dynamics are not as simple as often portrayed and are a barrier for the introduction of new technologies...
- Appliances – such as homemade stoves – (Mbaulas):
  - Use more than one fuel,
  - Produce more than one energy service,
  - Space heating is simultaneously supplied while cooking and water heating (could be over-supplied)
- Needed the model structure to accommodate this with flexible inputs and outputs...
Inclusion of externality costs

- Include tracking of local and global emissions
- Cause of damage not included in transaction costs – external to transactions
- Assigned an indicative externality costs
- Not included here, but an important application of increased resolution is to track the timing of emissions episodes.

Data collection issues addressed

- Data collected via specialist survey and CDA
- Typical problems overcome:
  - Timing and desegregation of energy service requirements
  - Typically important data for modeling is obscure
  - Lack of data on informal transactions or in-kind costs
  - Cost data including hire-purchase arrangements
  - Iterative co-ordination with modeling
- Still significant shortcomings – related to the modeling framework: uncertainty, more non-cost objectives etc.
Nkweletsheni – the case study

- Low population density
- Limited infrastructure and far from grid
- Not targeted for grid connection
- Community support for this study (part of a larger initiative)
- Dependant on fuel wood
- Apply first version of an appropriate modeling survey

Scenarios considered

<table>
<thead>
<tr>
<th>Scenario (ID)</th>
<th>Key constraints and features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Base case (BC)</td>
<td>No access to electricity, conventional existing technologies/appliances only</td>
</tr>
<tr>
<td>2. Stand-alone generation only (SAG)</td>
<td>No access to grid electricity, local electricity options (DG)</td>
</tr>
<tr>
<td>3. Grid electrification (GE)</td>
<td>None, access to the national electric grid, includes DG</td>
</tr>
<tr>
<td>4. Electrification with cost reflective electricity prices (EREP)</td>
<td>Same as GE, with time dependant grid electricity pricing.</td>
</tr>
<tr>
<td>5. Externalities (EX)</td>
<td>Same as GE, with inclusion of indicative health costs of emissions</td>
</tr>
</tbody>
</table>
Results: Base case

Final energy demand

Heat production by activity
**Results: Base Case**

Over production of heat (Note this was overstated when using std MARKAL)

![Bar chart showing heat production over years]

**Results: Stand Alone Generation (SAG)**

Output by lighting source

![Bar chart showing lumens by year and lighting source]
Results: Stand-Alone Generation (SAG)

Fuel use for lighting (Note: Different electrification economics due to load curve inclusion)

Results: Grid electrification

- As with SAG, electricity is used for:
  - Lighting
  - Entertainment
  - Low volumes
- Consistent with field data:
  - Uneconomic to use electricity for high thermal loads. After electrification, traditional fuel use often persists
  - In previous studies — used in national planning — electricity projections were significantly overstated for poorer communities
Electrification with Cost Reflective Electricity Prices (EREP)

Electricity ‘imports’ into the village — increased economic and market potential

Results: Externalities (EX)

Electricity usage
**Results: Externalities (EX)**

**Carbon Monoxide emissions**

![Graph showing Carbon Monoxide emissions over years]

**Results: EX Carbon**

- Decrease in electricity consumption; solar hot water heating;
  - increased LPG usage

**Annual CO₂ emissions**

![Graph showing CO₂ emissions over years]
Conclusions

- Captured effects of increased time resolution
- Time of day electricity costs may increase electricity consumption
  - Reduction of costs for electrification
  - Increased markets of appropriate DSM technologies/schemes (Driving development with markets)
- Including externalities (an indicator of social prerogatives) induces a large shift to electricity
  - (SA government move to subsidize a basic block of consumption)
- Fuel costs and usage of traditional appliances limits penetrations of new technology
- To reduce CO₂ emissions (while promoting social development) there was an increase in oil (LPG) consumption and new technology deployment
  - Under CO₂ trading (CDM) there are potential new market opportunities which may help foster development
- Sensible framework has been developed for baseline and additional cost analysis

Results: Final Energy Consumption

![Energy Consumption Graph]

- Base Case
- Externalities
- Stand-alone generation
- EREP
- Electrification
- Ex-Carbon
Conclusions

- We need to include multiple objectives to evaluate transitions
  - In the context of no developed theory and data shortages
- Demand for useful services also change as a function of access e.g. lighting: CFLs and candles
- Linkages between energy use and availability with new economic activity
- New modeling frameworks including GE and agent based
- Better co-ordination with survey to determine income and energy service elasticities
- Investigation of appropriate technologies in detail
- Should develop an appropriate array of externality costs
- Significant potential for use with CDM activities