Comparative Efficiency of Energy Services in Households: A DEA analysis in two Mexican communities

Jordi Cravioto, Eiji Yamasue
Ritsumeikan University, Japan

ABSTRACT: *Energy services (ES) have grown in presence in recent household energy consumption studies. This research revisits the concept and presents a data-envelopment-analysis assessment of household ES efficiency in terms of associated energy consumption. The role of household equipment penetration and equipment technology is discussed using these efficiency outcomes.*

Introduction

- Household-scale descriptions are crucial in energy research,
  - because overall energy consumption is reflected at the household
- In household-scale analyses, energy services (ES) are driving research interest,
  - because ES can disaggregate energy consumption (Sovacool, 2011)
  - and ES can link energy use with social aspects (Cravioto, 2017)

Energy services (ES)

- Most analyses have taken ES for end-uses (allocating physical/economical units)
- In reality, ES contain end-uses of energy in conjunction with other elements (Sovacool, 2011)
  - they represent a benefit for human well-being (Fell, 2017; Cravioto, 2014)
- ES have already been measured in a satisfaction scale and analysed in relation to material and well-being indices (Cravioto, 2014), but still many aspects are yet to be explored:
  - **how certain households can report higher levels of ES with modest energy consumption**
  - **the role of household equipment and technology in the most-efficient households**

PURPOSE

1. **Evaluate comparative efficiency of households using ES with respect to energy consumption**
2. **Analyse the role of household equipment and technology using such efficiency**

Method

Survey/questionnaire (sample size: 98 from two Mexican locations, retrieved in 2012)

- Four ES in a satisfaction scale: illumination, transport, communications and temperature regulation (Cravioto, 2014, 2017; Sovacool, 2011; V. Modi, 2006), using the following item:

  In a five-point scale, rate how satisfied or dissatisfied you are currently with the following ES at home?
  (1 being very dissatisfied and 5 very satisfied) _____

- Energy consumption / # household appliances / appliances' age (y) (appliance age is considered here a proxy of TECHNOLOGY)

Cuauhtémoc [income: 15,636 dls/year]

Data Envelopment Analysis

- Mathematical technique for comparative efficiency (Cook et al, 2007):

$$\max \; E_m = \frac{(\text{Virtual Outputs})_m}{(\text{Virtual Inputs})_m} = \frac{\sum_{r=1}^{s}(v_r y_r)_m}{\sum_{i=1}^{t}(u_i x_i)_m}$$

subject to

$$0 \le \frac{\sum_{r=1}^{s} v_r y_{rn}}{\sum_{i=1}^{t} u_i x_{in}} \le 1 \;,\; n = 1,2,\ldots,N,$$

$$u_{im}, v_{rm} \ge 0 \;,\; i = 1,2,\ldots,I \;,\; r = 1,2,\ldots,S$$

Zoquitlán [income: 2,208 dls/year]

- In this DEA model ES are outputs and energy consumption inputs: (they associate as shown in the table of spearman corr. below)

	Electricity	Gas	Petrol
Illumination	0.6		
Transport			0.64
Temp. regulation	0.46	0.544	
Communication	0.644		0.662

Results

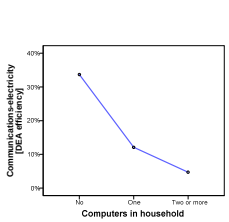
ILLUMINATION:

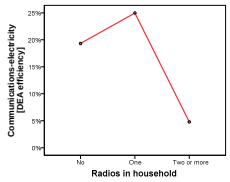
EQUIPMENT:

- Mid-range correlation of illumination and no. of lightbulbs (0.46),
- **turned negative when seen through ES-energy efficiency:**
  - ✓ **Total lightbulbs (-0.76)**
  - ✓ **bulbs per member (-0.73), Bulbs per room (-0.51)**

TECHNOLOGY:

- Better lightning technology correlated with higher illumination (0.31),
- **but it did not reflect in the ES-energy efficiency (probably consumption improvements are too small to be accounted)**
  - ✓ **% efficient lightbulbs (0.1)**





TRANSPORT

EQUIPMENT:

- **Ownership of more than one car did not have a significant effect on efficiency**

TECHNOLOGY:

- **Car technology also did not show correlation with transport efficiency:**
  - ✓ **car age (-0.05)**

COMMUNICATION:

EQUIPMENT:

Appliances

- **More appliances' penetration was also negative on the ES-energy efficiency:**
  - ✓ **TV, video player, computer (all similar to computer – see plot left below)**
  - ✓ Radio (inverted U: efficiency increases from not having to having at least one but it decreases after – see plot below)
- **For vehicles no significant effect on the efficiency**

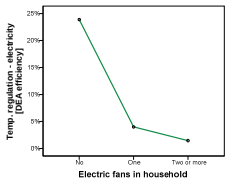
TECHNOLOGY:

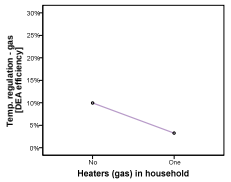
Appliances

- **Newer appliances did have an important effect on the efficiency of communication:**
  - ✓**TV (0.47), Radio (0.29), Computer (0.21)**
  - *but only TV resulted significant, technology of other appliances such as phone, DVD or printer was not relevant.

Vehicles

- **Better car technology also did not correlate with communication efficiency.**





TEMPERATURE REGULATION:

EQUIPMENT:

- **More equipment penetration was negative on temp. reg. efficiency**

For appliances, main tendency is negative:
- ✓ Iron, hairdryer (same pattern as computer –see plot)

For showering-related equipment, similar:
- ✓ Shower head, bath and boiler (same pattern as computer)

For heating/cooling equipment, partially similar:
- ✓Electric fan, AC, electric heater significantly associated with less efficiency (all similar to electric fan - see plot)
- *but central heating systems and gas heaters without significant effects (both similar to gas heater plot)

For cooking equipment, no relation:
- ✓ Stoves (gas and electric) did not have significant effects on efficiency

TECHNOLOGY:

- **Some appliances' technology had a meaningful effect on temperature regulation efficiency:**

Appliances
- ✓ Iron (.4), Hairdryer (.3)

Showering equipment
- ✓ Bath (0.37), Boiler (0.2), Shower head (0.2)

Heating/cooling space equipment
- ✓ Heating system (0.48), Heater (gas) (0.21), Fan (0.2)
- *But not AC / electric heaters, probably because in these locations there is no strong need for ac and thus no impact on the efficiency

Cooking equipment
- ✓Electric stove (opposite direction) (-0.3421), probably because newer electric stoves associates with richer households that mix cooking for heating space.
- *not so for gas stove

Conclusions

- **In general, higher penetration of appliances has a negative effect on the efficiency of any ES and its related energy consumption. This is plausible because higher access to consumption facilitators would create higher consumption.**
- **On the other hand (and contrary to common understanding) not all technology associated with better scores of efficiency. In fact, technology in general did not have a meaningful effect on ES efficiency, except for certain ES.**
- **The findings also suggest that temperature regulation is mainly concerned with heating (and not cooling) space in these Mexican locations. With this respect the most common way of heating is through gas, yet electricity takes certain importance through a couple of appliances (iron, hairdryer). Technology on gas heaters and showering equipment is the most meaningful.**
- **As for communication, tv and radios might be the most common way of communicating with outside, but computers are taking its importance. Technology is quite relevant for tv and to a lesser extent to radios and computers.**
- **Further research should aim to understand these findings in more detail and expand the analysis to cover other ES.**

References

cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2014) Energy service satisfaction in two Mexican communities: A study on demographic, household, equipment and energy related predictors. Energy Policy, 73, 110-126.

Cravioto, J. and Yamasue, E. (2017) Energy services and life satisfaction: a study on households in two Mexican communities. Energy for Society: 1st International Conference on Energy Research & Social Science. Sitges, Spain. Apr 2017.

Cooper, W.W., Seiford, L.M. and Tone, K. (2007). Data envelopment analysis: A compre hensive text with models, applications, references and DEA-solver software. Springer Science and Business Media.

Fell, M. J. (2017) Energy services: A conceptual review. Energy Research & Social Science, 27, 129-140.

Modi, V., McDade, S., Lallement, D. and Saghir, J. (2006) Energy services for the millennium development goals. New York: Energy Sector Management Assistance Programme, United Nations Development Programme. UN Millennium Project and The World Bank.

Sovacool, B.K. (2011a) Conceptualizing urban household energy use: Climbing the Energy Services Ladder. Energy Policy, 39(3), 1659-1668.

Acknowledgement: **Global Center of Excellence of the Graduate School of Energy Science, Kyoto University and the Environment Research and Technology Development Fund (S-16) of the MOEJ**

Contact

Circular use of Materials Lab (Yamasue lab)
College of Science and Technology, Ritsumeikan University
1-1-1 Nojihigashi, Kusatsu city, Shiga 525-8577 Japan
Tel. +81-77-561-4866
Email: **jordi-c@gst.ritsumei.ac.jp**

For more information on our research
http://www.ritsumei.ac.jp/~yamasue/index.html