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**MEASURING ENERGY POVERTY IN SENEGAL: A FUZZY MULTIDIMENSIONAL
ENERGY POVERTY INDEX (FMEPI)**

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INCENTIVE FOR RESEARCH ON ENERGY POVERTY

- Major area of concern for the economic development of Africa
- Future demographic explosion
- Households living conditions



SENEGAL:

- Electricity access (%) (World Bank, 2016)

Area	Senegal	Urban	Rural
2016	64.50	87.70	38.30

- Frequent electrical load-shedding: Alternatives (Candle used by 58.0% of households and torch used by 24.6% of households according to Agence Nationale de la Statistique et de la Démographie, 2015).
- Biomass represents 42% of the final energy consumption (Agence Nationale de la Statistique et de la Démographie, 2013): firewood (59%) and charcoal (26%).



ENERGY POVERTY

- IEA, 2010 “Energy poverty as a **lack of access to modern energy services.**”
- Cited :AFREC, 2016; Apere and Karimo, 2014; Bensch, 2013; Bhatia and Angelou, 2015; Nussbaumer et al., 2011, 2012 and 2013; Pelz et al., 2018; Practical action, 2010 and 2012)

MEASURING ENERGY POVERTY

1. Per capita energy required to meet the basic energy needs of cooking, lighting and space heating
2. Energy or fuel poverty line calculated from an income or expenditure
3. Access to energy services/deprivation

ENERGY POVERTY MEASUREMENTS

□ UNIDIMENSIONAL MEASUREMENTS :

- Minimum energy consumption threshold (Modi et al., 2005; UN-AGECC, 2010),
- Income-invariant energy demand (Barnes et al., 2011)
- Borderline income-poor energy consumption (Foster et al., 2000).

□ MULTIDIMENSIONAL MEASUREMENTS :

- Energy Development Index (IEA, 2010)
- Multidimensional Energy Poverty Index (OPHI- Nussbaumer et al., 2011)
- Correlation Sensitive Energy Poverty Index (Bensch, 2013)
- Total Energy Access (Practical action, 2012)
- Multi-tier Framework for measurement of access to energy (World Bank- Angelou and Bhatia, 2015).

LIMITS OF MULTIDIMENSIONAL MEASUREMENTS

- Multidimensional measurements identify only borderline energy poor household:
 - i) Dichotomisation of the households into energy poor and non-energy poor;
 - ii) Different dimensions or sub-dimensions including in the modelling process due to the lack of knowledge on what represents rigorously the basic energy service;
 - iii) Limited understanding of the nature of energy poverty due to heterogeneity existing between households;

TOWARDS A NEW MULTIDIMENSIONAL ENERGY POVERTY INDEX !

The advantages of Fuzzy Logic

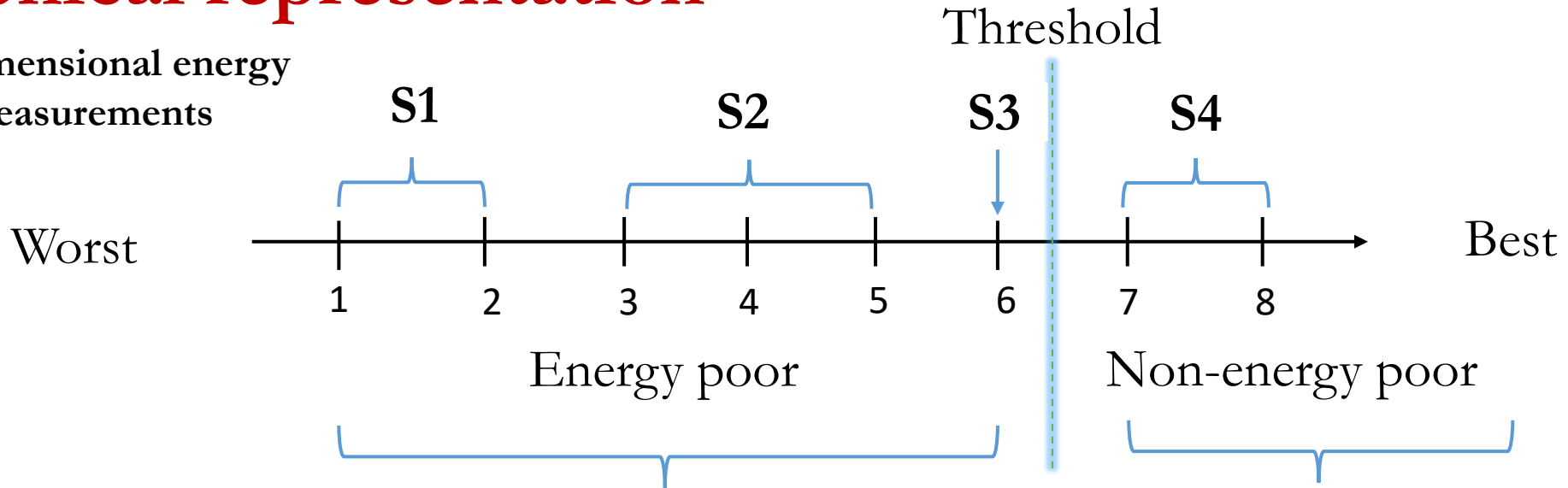
Scenario of energy poverty

Scenarios	Cooking	Lighting	Appliances: fridge	Radio	Television/ Telecommunication
S1: None achievement	Biomass	Biomass	N/A	Battery/no	N/A
	Biomass	Torch/oil lamp	N/A	Battery/no	N/A
S2: Only one achievement	Clean cooking fuel	Biomass	N/A	Battery/no	N/A
	Clean cooking fuel	Torch/oil lamp	N/A	Battery/no	N/A
	Biomass	Electricity/Solar or other modern energy	no	Battery/no/electricity	no

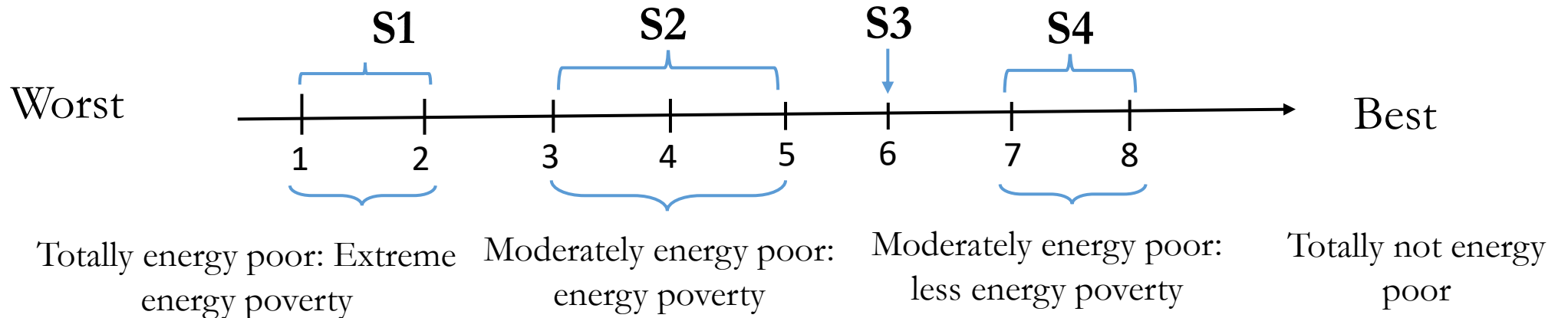
Scenarios	Cooking	Lighting	Appliances: fridge	Radio	Television/ Telecommunication
S3: Two achievements	Clean cooking fuel	Electricity/Solar or other modern energy	no	Battery/no/electricity	no
S4: More than two achievements	Biomass	Electricity/Solar or other modern energy	Electricity, Solar or other modern energy/no	Electricity, Solar or other modern energy/no	Electricity, Solar or other modern energy/no
	Clean cooking fuel	Electricity/Solar or other modern energy	Electricity, Solar or other modern energy/no	Electricity, Solar or other modern energy/no	Electricity, Solar or other modern energy/no

Graphical representation

Usual multidimensional energy poverty measurements



Fuzzy multidimensional energy poverty measurement



Fuzzy Multidimensional Energy Poverty Index (FMEPI)

- Fuzzy sets theory:

Theory of Georg
Cantor (1874)

$\left\{ \begin{array}{l} \text{"The object is member of the set"} \\ \text{"The objet isn't memeber of the set"} \end{array} \right.$

Fuzzy Sets Theory
(1965)

$\left\{ \begin{array}{l} \text{"The object is a full member"} \\ \text{"The object is a partial member"} \\ \text{"The object isn't a member"} \end{array} \right.$

- $\tilde{A} = \{(x, \mu_{\tilde{A}}(x) / x \in \theta)\}$

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & \text{if } x \text{ doesn't belong to } \tilde{A} \\ f(x) & \text{if } x \text{ belongs partially to } \tilde{A} \\ 1 & \text{if } x \text{ belongs fully to } \tilde{A} \end{cases}$$

$\mu_{\tilde{A}}: \mathbb{R}^+ \rightarrow [0; 1]$

Energy poverty in Senegal: what are the relevant dimensions?

(Dimensions and Variables extracted from Nussbaumer et al., 2011)

Dimension	Variable	Modalities
Cooking	Type of cooking fuel	Modern cooking fuel
		Traditional cooking fuel
	Indoor pollution	Food cooked on clean cooking fuel
		Food cooked on stove or open (no hood/chimney) if using traditional cooking fuel
Lighting	Having electricity	Yes
		No
Services provided by means of household appliances	Having a Fridge	Yes
		No
Entertainment/education	Having a radio or television	YY /YN
		NY/NN
Communication	Having a phone land line or a mobile phone	YY/YN
		NY/NN

METHODOLOGY

- Measure energy poverty using fuzzy sets approach developed by Zadeh (1965) and applied for the case of poverty in many studies (Cerioli and Zani, 1990; Cheli and Lemmi, 1995; Qizilbash, 2003; Chatterjee, Mukherjee and Kar, 2014).

$$x_{ij} = \mu_B(X_j(h_i)) = \mu_B(X_j^{(k)}) = \begin{cases} 0 & \text{if } X_j(h_i) = X_j^{(1)}; k = 1 \\ \mu_B(X_j^{(k-1)}) + \frac{f(X_j^{(k)}) - f(X_j^{(k-1)})}{1 - f(X_j^{(k)})} & \text{if } X_j(h_i) = X_j^{(k)}; k > 1 \end{cases} \quad (1)$$

- Weighting system: Cheli and Lemmi (1995) suggests the following procedure:

$$\mu_B(h_i) = \frac{\sum_{j=1}^m x_{ij} w_j}{\sum_{j=1}^m w_j} \quad (2)$$

$$w_j = \ln\left(\frac{1}{\mu_B(X_j(h_i))}\right) \text{ with } \overline{\mu_B(X_j)} = \frac{1}{n} \sum_{i=1}^n \mu_B(X_j(h_i)) = \frac{1}{n} \sum_{i=1}^n \mu_B(X_j^{(k)})$$

CONTRIBUTIONS IN THE LITERATURE OF ENERGY ECONOMICS

- Household energy context and Climate characteristics
- First application of theory of fuzzy set in order to assess energy poverty.
- Fuzzy Multidimensional Energy Poverty Index (FMEPI)

Energy poverty affects over
2 billion people

Thank for your attention

