AEMI FORUM: ENERGY POVERTY AND SMALL SCALE RENEWABLE ENERGY

Jakarta, 3 – 4 June 2015

DISCUSSION PAPER

A. FORUM OBJECTIVE

1. The task of AEMI in the energy poverty area is to develop relevant policy recommendations for the ASEAN Plan of Action for Energy Cooperation (APAEC) (2016-2020). This would focus on improving access to electricity on grid (notably through the ASEAN Power Grid), as well as off grid. This forum is convened to plan AEMI's work in this topic area for the coming two years, in particular to agree on an analytical approach and division of labor among its participants from ASEAN research institutions. A follow-up forum in this topic area will be convened in 2016 or 2017 to finalize the results of the work.

2. More specifically, the research to be undertaken will be designed to address the following objectives:

   (a) To provide policy recommendations for the new APAEC (2016-2020)
   (b) To evaluate how ASEAN can enhance electricity access with special reference to off-grid renewable energy solutions.
   (c) To assess how off-grid and mini-grid can be promoted to complement the APG mechanism with special reference Indonesia and Philippines.
   (d) To highlight the potential role of ASEAN's energy poor island communities as a launch market for renewable energy and an opportunity for ASEAN to take a lead role in a global context.
   (e) To assess the climate aspect of rural electrification, in particular whether remote energy poor communities can leapfrog directly from no electricity to local supplies of renewable energy.
   (f) To assess the status of households and community welfare before and after gaining access to electricity by conducting a fieldwork study in selected villages (covering on grid, off grid, and mini grid).
   (g) To assess the sustainability of electricity access, including technology selection, maintenance and operation, standardization and coordination, utilization of capacity, local ecology, investment, pricing and payment solutions.

A. ASEAN Energy Poverty and Rationale for Small-scale Renewables

3. In 2012, 140 million people in ASEAN (equivalent to 22.6% of the region's total population) do not have access to electricity. Surprisingly, this number has risen from about 127.4 million in 2010. This indicates that ASEAN as a whole has not progressed towards meeting the Sustainable Energy for All (SEA4ll) objectives. This initiative was launched by the UN General Assembly in September 2011. As seen from Table 1, the ratios of access to

electricity in rural areas lags far behind the urban areas in Cambodia, Indonesia, Laos, Myanmar, Philippines and Vietnam.

4. According to the International Energy Agency (IEA), energy poverty is defined as lack of access to modern energy services, i.e. access to electricity and clean cooking facilities. Similarly, Reddy and Reddy (1994) as cited in Masud et al. (2007:47), define energy poverty as "the absence of sufficient choice in assessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development". Thus without serious effort by the ASEAN member countries to combat energy poverty, it will be difficult for ASEAN to achieve "RICH" status by 2030.[1]

Table 1. Electricity Access 2012

Country	Population without electricity, millions	National Electrification rate (%)	Urban electrification rate (%)	Rural electrification rate (%)
Brunei Darussalam	0	100	100	99
Cambodia	10	34	97	18
Indonesia	60	76	92	59
Laos	1	78	93	70
Malaysia	0	100	100	100
Myanmar	36	32	60	18
Philippines	29	70	89	52
Singapore	0	100	100	100
Thailand	1	99	100	99
Vietnam	4	96	100	94

Source: IEA, World Energy Outlook 2014

5. On the other hand, a UNDP (2005) study shows that providing access to modern energy can enhance countries' attainment of the Millennium Development Goals (MDGs). Kanagawa and Nakata (2008) show that energy has close relationship with poverty indicators such as health, education, income and environment. By using the rural level data in Bangladesh, Barnes et al. (2010) found that the use of electricity significantly improves household incomes. Similar, positive association was found by Kooijman – van Dijk and Clancy (2010) using rural level data in three countries, Bolivia, Tanzania and Viet Nam. They found that electricity access in rural areas directly provided both non-financial benefits and financial benefits to rural household such as improving quality of goods and services. Electricity access also reduces travel time and waiting time. Then, electricity access enables household to use mobile phone and electric machines for sewing and working wood (Kooijman – van Dijk and Clancy, 2010).

6. Studies have also shown that there is a connection between electricity access and welfare (Munasinghe 1988; Reiche, Covarrubias & Martinot 2000; Peng & Pan 2006; Al Mohtad

1 RICH = Resilient, inclusive, competitive and harmonious. ADB (2014:xxiv) states that "*resilience* refers to the capacity to handle volatilities and shocks from within or outside the region, reducing the likelihood of economic crises; *inclusiveness* refer to the need for ASEAN to achieve equitable economic development, providing opportunities through cooperation strategies that reduce income gaps within and across countries, and promoting citizen welfare; *competitiveness* requires a business environment where successful firms operate in efficient markets under effective national and regional regulation; and *harmony* stems from environmentally sustainable development and growth, with proper consideration of the need to mitigate and adopt to climate change".

2006; Kanagawa & Nakata 2008). Reiche, Covarrubias & Martinot (2000) investigated the social impact of a rural electrification program on increasing standard of living, reducing traditional energy consumption such as fire wood, leading to better health and environmental conditions, increasing job opportunities, and enhancing business productivity. Kanagawa and Nakata (2008) studied electricity access in poor India region and showed that electricity access had a direct and indirect impact on poverty indicators such as health, education, income and the environment.

7. There are three ways to improve the electrification ratio (IEA, 2011): (i) grid extension, (ii) mini grid,[2] and (iii) off-grid. In cities or in regions with high population density, grid extension can draw on existing infrastructure to provide the lowest cost option. Mini grid can be low voltage and it can be fed by small power generator. Cooperative and local business entities can manage it (IEA, 2011). Finally, the off-grid electricity can be promoted in remote areas where settlements are scattered and it is impossible to develop a grid extension or mini grid (IEA, 2011). At the ASEAN level, ASEAN Power Grid is one of the mechanisms for alleviating energy poverty, but it may have many limitations. Table 1 shows, energy poverty is concentrated in rural areas where grid extension has less of an advantage. Because most energy-poor households are located in rural and remote areas, promoting small-scale renewables can be an effective way to increase the electrification ratio. As seen from Table 2, different types of small-scale renewable energy have different comparative advantages in supporting daily life and economic activities. It is therefore also important to consider carefully exactly which type of renewable energy source to install when trying to use renewable energy to alleviate rural energy poverty.

[2] With range of capacity between 10 – 1,000 kilo watt (IRENA, 2012)

Table 2: Application of Renewable Energy for Supporting Economic Activities

Type of technology	Lighting/ Refrigerator	Communication	Cooking	Heater/ Cooler	Micro industry	Water pump
Solar Home System (SHS)	√	√			√	
Pico Solar Photovoltaic (SPV)	√	√				
Solar thermal				√		
Solar cookers			√			
Solar crop dryers				√		
SPV Pumps						√
Small hydro	√	√				
Small wind		√			√	√
Mechanical wind pumps						√
Household-scale biogas digester	√	√	√	√		
Biomass gasifier	√	√			√	√
Improved cook stove (ICS)			√			

Source: IRENA (2012)

B. Methodology

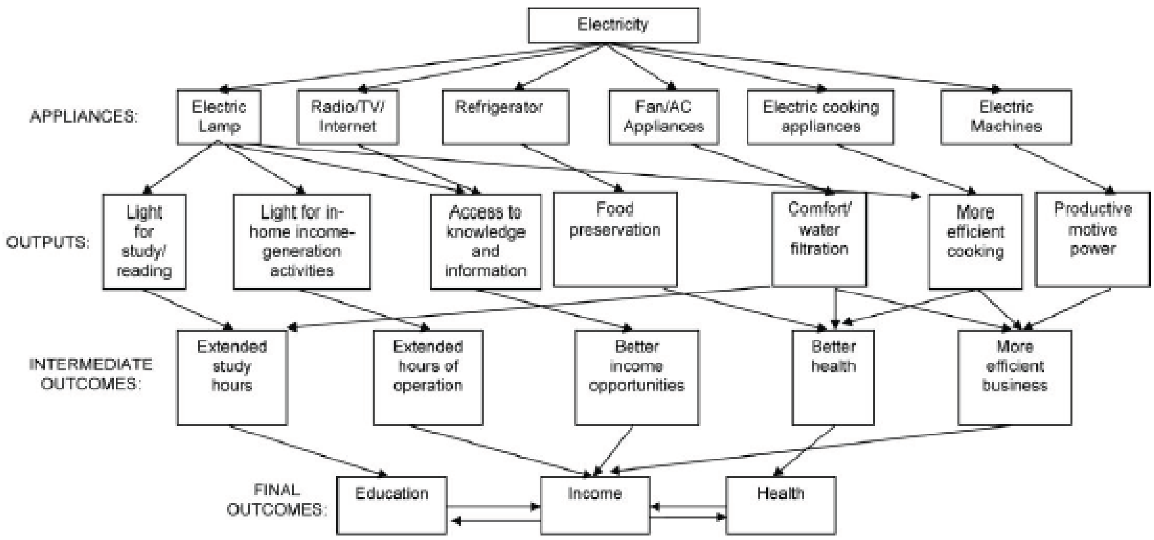
C.1 Country Focus

8. Five of the ASEAN countries have large numbers of people without electricity access: Indonesia, Myanmar, Philippines, Laos, and Cambodia. In addition, we also include Vietnam in the study for two major reasons. First, there will be the APG new interconnection project in 2017 between Vietnam and Cambodia. Thus, Indonesia and Malaysia will be the beneficiaries of APG from the eastern part of APG while Vietnam and Cambodia represent the northern part of APG. Second, Vietnam represents a success story, because in spite of a lower GDP per capita than Indonesia and the Philippines, the ratio of electrification in rural areas is approaching 100%. Thus, it is necessary to understand this achievement. Appendix 1 provides an overview of the situation in Vietnam.

C.2 Framework

9. There are five elements of assessment that we are going to conduct: (i) understanding the extent to which the renewable energy policy of the six countries draws on policy frameworks, targets or other policy instruments developed by ASEAN as a multilateral organization; (ii) understanding the characteristics of energy poor households; (iii) understanding and evaluating the selection criteria that government sets in providing electricity access (on grid, mini grid and off grid); (iv) assessing the impact of electricity access both quantitatively and qualitatively; and (v) assessing the sustainability of off-grid renewable energy. However, Khandker et al (2013) argued that it is difficult to measure the direction and magnitude of outcomes in relation to the specific electrification programs introduced, due to the complex relationship between electricity equipment, output and intermediate outcomes. As seen from Figure 1, gaining access to electricity has lead households to buy electric equipment such as lamps, radios, television sets, refrigerators, rice cookers and small scale electric machines. They produce different outputs such as for lighting, information, more efficient cooking, and food preservation. Intermediate outcomes from those outputs such as extended study hours, extended hours of operation, better income opportunity, better hygiene, better health, better information and communication and more efficient business. Thus the final outcomes will be improvement in education, income and health.

Figure 1: Transmission of Electricity Benefits to Welfare



Source: Khandker, Barnes & Samad 2013, pp. 668

C.3 Sample selection

10. The main objective of the survey is to collect data at the household level, then we plan to assess the impact of electricity access (focus on small-scale grids) on social welfare.[3] The unit of analysis is households in remote areas that gain access to electricity from renewable energy during the project period and households who will be beneficiaries or potential beneficiaries of the off grid connection. We prepared three strategies for data collection. In strategy A, the control group is households that do not have electricity access, while the treatment group is consists of nearby households that will have access to electricity the following year. We collect a random sample of about 50 households from each village for each period.

[3] Refer to Appendix 3 for further information regarding the survey questionnaire.

Strategy A

Group	**Time t**	**Time t + 1**
Control	Do not have electricity	Do not have electricity
Treatment	Do not have electricity	Have electricity

Note: we survey the same households in time t + 1

11. In strategy B, we are not sure whether the treatment group will obtain electricity in time t + 1 or not, thus, we obtain households that have electricity and do not have electricity in time t. From a technical point of view, strategy A is more reliable than strategy B, because we compare the same household at time t and t + 1. However, if at time t + 1, the treatment group fails to obtain electricity, as in strategy B, there will be little point in the study. We can combine strategy A and B into strategy C. It seems that strategy C will provide low risk in terms of the success of the impact assessment, but it is necessary to expand the sample size. We currently aim to pursue strategy A, but this will depend on whether collaborators are able to identify suitable locations in their countries.

Strategy B

	Time t	Time t + 1
Group M	Have electricity	Have electricity
Group N	Do not have electricity	Do not have electricity

Strategy C

	Time t	Time t + 1
Group X	Have electricity	Have electricity
Group Y	Do not have electricity	Have electricity
Group Z	Do not have electricity	Do not have electricity

12. Before conducting fieldwork, it is necessary to obtain information from the national electricity authority or international organizations or NGOs with relevant projects about villages that have access to electricity and do not have access on electricity. It would be good if we can select locations where the two groups (have and do not have electricity) neighbor each other and they are far away from the APG network and national grids. Then, we also need to obtain information regarding the main source of electricity supply. It is good if we can cover a variety of renewable energy sources such as hydro power, solar panel and biomass.

C.4 Method of Analysis

C.4.1 Qualitative analysis

13. We will divide the qualitative analysis into two three elements. First, we will assess the role that ASEAN-wide policy instruments are playing at the national level of the ASEAN countries, based on the initial literature review/overview of policy at national level carried out by the collaborators. Second, we will assess the impact of electricity access on education, health, social activity, environment, economic activity and gender dimension. Thirdly, we assess the sustainability of existing small-scale renewables in terms of: (i) technology selection; (ii) maintenance and operation; (iii) standardization and coordination; (iv) use of capacity; (v) environment/ecology; (vi) investment; (vii) pricing; (viii) payment solution. The information will be obtained from household, community, and local government level. Appendix 2 provides more information.

C.4.2 Quantitative analysis

A. Statistical analysis

14. We can apply descriptive statistics and parametric (or non-parametric) test to investigate the differences in selected indicators (expenditure, health, and education) between the two groups (with and without) or among groups with difference type of electricity access.

B. Econometric approach

15. We propose two econometric approaches that can be applied to our data: (i) Seemingly unrelated regression (SUR); and (ii) the fixed effect model. Appendix 3 provides more details.

C. Research outline[4]

16. The proposed research outline is divided into two phases based on the fieldwork activity. After conducting the first fieldwork the report outline is agreed as follows:

1. National interest in eradicating energy poverty and promoting renewable energy
    a. Why small scale renewable energy important
    b. What is the energy poverty situation throughout ASEAN
    c. What do ASEAN nation plan to do about it
    d. How small scale renewable energy can reduce poverty

2. Brief overview on small scale renewable energy
    a. Current situation
    b. Prospect and trend
    c. Target
    d. Financial and investment

[4] The research outline may slightly change, especially on the sustainability assessment.

3. Methodology
    a. Location description
    b. Sampling technique (using the convenience sampling technique, with a minimum sampling of 100 households, chosen according to selection criteria in strategy A)

4. Empirical analysis – First Fieldwork
    a. Descriptive Statistics (based on the questionnaire)
    b. Qualitative assessment (based on updated interview questions, Appendix 2)
        i. Local-Provincial-Central Government
        ii. State Own Electricity Company (SOEC)
        iii. Village
        iv. Private Sector

After conducting the <u>second fieldwork</u>, the following points will be included in the second report:

5. Empirical analysis – Second Fieldwork
    a. Descriptive Statistics (comparing changes between first and second fieldwork)
    b. Qualitative assessment (comparing changes between first and second fieldwork)
        i. Local-Provincial-Central Government
        ii. State Own Electricity Company (SOEC)
        iii. Village
        iv. Private Sector
    c. Sustainability assessment (country level analysis)
        i. technology selection
        ii. maintenance and operation
        iii. standardization and coordination
        iv. ecology/environmental assessment
        v. investment and pricing policy

6. Econometric assessment – Impact assessment[5]
    a. Building model (difference in difference)
    b. Model Diagnostic
    c. Empirical results
    d. Conclusion

7. Sustainability assessment for 6 countries studies[6]

8. Policy Implications and Recommendations for the ASEAN (key issues, including)[7]
    a. Implication for the new APAEC (2016-2020)
    b. The role of AEMI in developing off grid connection.
    c. Promoting complementarities between APG and off grid
    d. ASEAN as a role model of off-grid in a global context.
    e. Promoting the welfare impact from electricity access
    f. Ensuring sustainability of electricity access

[5] Impact assessment will be conducted by Maxensius Tri Sambodo
[6] This analysis will be prepared by Indra Øverland
[7] This section will be prepared by Indra Øverland

D. Tentative time frame 2015 – 2017

Date	Keyword	Activity	Person in charge
June 2015	AEMI Forum I	Discussing research design and expert meeting. Agreement on content and methodology of study	Maxensius Tri Sambodo
9 June 2015	Questionnaire	Distribute revised version to collaborators for final round of discussion over email.	Maxensius Tri Sambodo
30 June 2015	Questionnaire	Finish email discussion	Indra Overland
30 June 2015	Data collection	Identify locations for data gathering	Collaborators
31 July 2015	Country reviews	Finalize guidelines for what collaborators should include in their country reviews.	Indra Overland
31 August 2015	Country reviews	Finish national level reviews of renewable energy situation	Collaborators
September - October 2015	Data collection I	Each country team conducts fieldwork to gather baseline data.	Collaborators
15 December 2015	Country report I	Submit baseline data with descriptive analysis and explanation of choice of location etc.	Collaborators
31 January 2016	Aggregate baseline report I	Synthesizing all country reports	Indra Overland
March 2016	Questionnaire	Formulate new questions on sustainability of renewable energy (management, financing, repairs)	Indra Overland
31 August 2016	Data collection II	Each country team conducts fieldwork to gather post-treatment data.	Collaborators
September 2016	Country report II	Post-treatment data and analysis	Collaborators
November 2016	Draft aggregate report II	Synthesizing all country reports and adding analysis	Maxensius Tri Sambodo and Indra Overland
November 2016	AEMI Forum II	Study results and policy recommendations	Indra Overland
15 December 2016	Final Report	Report preparation	Indra Overland and Maxensius Tri Sambodo
January 2017	Op-eds	Publish op-eds in newspapers in ASEAN countries	Indra Overland
June 2017	Academic articles	Submit 2 articles to peer reviewed journals	Indra Overland and Maxensius Tri Sambodo

APPENDIX 1

ASEAN PERSPECTIVES

During the forum discussion, the collaborator from each country provided basic information regarding the rural electrification program as in the example in Box 1. The study will include such overview of the situation in relevant ASEAN nations.

Box 1
Rural electrification in Vietnam

(1) National target: Achieve over 99% electrification by 2020 (given in Prime Minister Decision No 2081 QD/TTg on Rural, Mountainous and Island Electrification Program for the Period 2013-2020 (8 November 2013). Specific objectives are:
  a. Supply electricity to 57 communes that are currently without electricity
  b. Supply electricity to 12 thousand hamlets of these 57 communes
  c. Number of households that will be supplied electricity is about 1,290 thousand in these 57 communes.

(2) Objectives of the first period (2013-2015).
  a. Supply electricity to about 140 thousand households in 2,500 hamlets of 40 communes

(3) Objectives in the second period (2016-2020)
  a. Supply electricity to about 1,126 thousand households in 9,640 hamlets of 17 communes
  b. About 21,300 households will be supplied electricity off-grid

(4) Investment: Total required investment: 28,809 billion dong (1.5 billion USD). Of which 27,328 billion dong for national grid extensions and upgrades, and 1,481 billion dong for off-grid (renewable energy)

(5) Key players are Ministry of Industry and Trade, Vietnam Electricity, provincial people's committee, donors such as WB, ADB, KfW, JICA

(6) Key barriers: including financing, technology; and possible solutions for rural electrification: e.g., financial, technical, institutional.

(7) Roles of RE in rural electrification: small hydropower, solar PV, small wind, etc. There is a project supplying renewable electricity for communes located in remote areas in the following provinces: Tra Vinh, Soc Trang, Lai Chau and Dien Bien. ADB will provide loan of 1,775 billion dong to this project.

(8) According to the EVN's report (30 Sept 2014), There are only 42 communes having no electricity among 54 communes in early 2013. Of which EVN is responsible for 27 communes and Provincial People's Committees are responsible for 15 communes. More specifically EVN is responsible for 16 communes in Nghe An province and 11 communes in Lai Chau while Provincial People's Committees are responsible for 6 communes in Cao Bang; 4 in Dien Bien and 5 in Quang Nam.

APPENDIX 2

SURVEY[8]

In-depth interview

Local-Provincial-Central Government
Agenda for promoting electricity access
The role of renewable energy
Managing sustainability of electricity supply at small scale level
Budget in promoting electricity access
Organization and institutional setting in promoting off grid connection
State Own Electricity Company (SOEC)
Programs on electrification ratio (APG, on grid, mini grid, and off grid)
Involvement of SOEC in promoting off grid connection
Village
Potential source of renewable energy
Challenging in promoting renewable energy
Managing sustainability of electricity access
Understanding economic and social impact on off grid to the community
Understanding the potential environmental and benefit
Understanding the potential impact on gender issue
Private Sector
Investment prospect renewable energy especially on off grid
Obstacles and expectation

[8] The in-depth questions may be changed after obtaining feedback from collaborators by the end of June 2015

Questionnaire – at the Household Level[9]

Location		
1	Country	
2	Province	
3	District/City	
4	Sub-district	
5	Village	

Household			
1	Name	3	Age head of household
2	Number of family member (*including head of household*)	4	Gender

Employment Status for Head of Household
1. Number of working day in a week: ……day 2. Number of working hours in a week: …… hour 3. Number of working house in a week: (day time) ...... hours; and (night time) ...... hours 4. Main employment status... 5. Salary per month from main job.... 6. Any side job..... and what is it? 7. Any family member working in foreign country? How many?

Housing
Type of roof
Type of wall
Type of floor
Total area of floor ……… m^2
Source of lighting i. Kerosene ii. Diesel iii. Battery torch iv. Candle
Type of cooking energy i. Firewood ii. Kerosene

[9] The questionnaire may be changed after obtaining feedback from collaborators by the end of June 2015

iii. Gas (LPG)
iv. Other….

Total expenditure for per month for:

1. Electricity
2. Kerosene
3. Fire wood

Food and Non-Food Expenditure (in the last week)

Food expenditure

i. Rice
ii. Other carbohydrate
iii. Fish, prawn, etc.
iv. Meat
v. Milk
vi. Egg
vii. Peanut
viii. Vegetable
ix. Fruit
x. Cooking oil
xi. Beverages

Non-Food

1. Housing
2. Health
3. Education
4. Transportation
5. Cloths
6. Electronic

Social Protection Program

1. Cash transfer
2. Free access on health
3. Free access on education
4. Access on micro credit
5. Access to free food
6. Social works
7. Foreign worker (any family member)

Electricity Access

1. Has access on electricity? When?
2. Source of energy for off grid connection
3. Installation cost
4. Amount of monthly payment

If the answer on question no 1 is no, then

1. What are the reasons do not access on electricity?

2. What efforts have been done to obtain electricity?

Information on electronic equipment
What kind of electronic equipment do you have and how many? (Radios, Television, Mobile phone, rice cooker, water heater, electric stove, water pump, etc.)

Gender Questions
1. How many female in the family? 2. What is the highest education level? 3. What is the lowest educational level? 4. Does she responsible to collect firewood? 5. How electricity access can make their life much easier?

Health information
1. Any health problems (focus on eyes and respiration), how long? 2. Does it affect economic activities, how **3.** Any effort to see doctor, how

Education (above 5 years old)
1. The highest education level in the family 2. Having access on information (newspaper, etc.) **3.** The average number of hours for studying (studying at night)

Questionnaire - At the Village Level

Information At Community Level
1. Any school nearby, what level 2. Public health center, how far 3. Grid connection, how far 4. Traditional market, how far 5. Telecommunication network 6. Public transport **7.** The average price of crops

Notes:

APPENDIX 3

ECONOMETRIC MODEL

A. Seemingly unrelated regression (SUR)

We developed an econometric model to assess quantitative impact of electricity access to people welfare. We can apply this strategy in the first both for Strategy B and Strategy C. We assume that increasing in welfare can be captured by increasing in household's expenditure both on food and non-food. We developed the model as follows:

$$Y_1 = x_1^{'}\beta_1 + U_1 \qquad 1)$$

$$Y_2 = x_2^{'}\beta_2 + U_2 \qquad 2)$$

Where Y_1 represents food expenditure and Y_2 represents non-food expenditure (we exclude energy spending from non-food expenditure). We have similar independent variables for the two equations namely: number of family member, number of working hours, total floor area, electricity access (1 for has access; 0 for no access), access to anti-poverty program such as rice, free health service, cash transfer, and other program. We defined electricity access both access through on-grid, off-grid, and mini grid. Because both food and non-food expenditure are connected, the error terms from the two equations are correlated. We can gain more efficient estimators by estimating the two equations jointly. Then we conducted seemingly unrelated regression (SUR).

B. The Fixed Effect Model

In the second year, we conducted the similar survey to the same households that we surveyed in the first year. We can apply this method for Strategy A, B and C. We can apply the Khandker et al (2013) model. We formulated the output on electricity access as follows:

$$Y_{ijt} = \beta^y X_{ijt} + \gamma^y V_{jt} + \delta_h^y E_{Hijt} + \delta_k^y E_{Kijt} + \delta_v^y E_{Vjt} + \chi^y T_t + \varepsilon_{ijt}^y \qquad 3)$$

where t indicates time index (0 for baseline-year 2015, and 1 for 2016/17); Y_{ijt} represent output (total real expenditure, we deflated the nominal value by consumer price index) for household i in village j; E_{Hijt} is electricity access – *on grid* (1 if household i in village j has electricity connection and 0 otherwise); E_{Kijt} is electricity access – off grid (1 if household i village j has electricity connection and 0 otherwise); E_{Vjt} is a status of electricity access in the village level *on grid* (1 if village j has connection on grid connection and 0 otherwise); X_{ijt} is the characteristic of household such as number of family member, access on rice for the poor, and floor area; V_{jt} is the village characteristics such as grid network, and T represents time period (2015 and 2016/17); $\beta^y, \gamma^y, \delta_h^y, \delta_k^y$ and δ_v^y are the parameter estimate from equation (1); and ε_{ijt}^y is a *non-systematic error.*

However, there is a problem when we directly estimate the equation (3). The variables E_{Hijt}, H_{Kijt}, E_{Vjt} and Y_{ijt} are simultaneously determined by a group of characteristics both observed and unobserved. For example, decision to have connection on electricity is not only affected by infrastructure condition especially the on grid (V_{jt}), but also by household characteristics (X_{ijt}). For example, poor households do not have capacity to pay connection fee. This is not only because of low of income level but also due to the number of family member. Thus, equation for on grid and off grid connection can be written as follows:

$$E_{Hijt} = \beta^e X_{ijt} + \gamma^e V_{jt} + \chi^e T_t + \varepsilon^e_{ijt} \quad (4)$$
$$E_{Kijt} = \vartheta^f X_{ijt} + \vartheta^f V_{jt} + \chi^f T_t + \varepsilon^f_{ijt} \quad (5)$$

Similarly, the equation at the village level can be presented as follows:

$$E_{vjt} = \gamma^v V_{jt} + \chi^v T_t + \varepsilon^v_{ijt} \quad (6)$$

Thus for the outcome equation, ε^y_{ijt} is represent the combination of three error terms components:

$$\varepsilon^y_{ijt} = \mu^y_j + \eta^y_{ij} + e^y_{ijt} \quad (7)$$

where μ^y_j and η^y_{ij} are represent the unobserved village condition and unobserved household characteristic, in addition e^y_{ijt} is a *non-systematic error* that are not correlated with the two error terms. Further, the error components on equation (4), (5) and (6) can be represented as follows:

$$\varepsilon^e_{ijt} = \mu^e_j + \eta^e_{ij} + e^e_{ijt} \quad (8)$$
$$\varepsilon^f_{ijt} = \mu^f_j + \eta^f_{ij} + e^f_{ijt} \quad (9)$$
$$\varepsilon^v_{jt} = \mu^v_j + e^v_{jt} \quad (10)$$

There is possibility of correlation among $\varepsilon^y_{ijt}, \varepsilon^e_{ijt}, \varepsilon^f_{ijt}$, and e^v_{jt} then the variables $E_{Hijt}, E_{Kijt}, E_{vjt}$ and Y_{ijt} can be correlated due to unobserved factors at village and household level. This can cause an endogeneity problem. This can be happened because *on grid* access can be found in villages that have good access on road and those village will obtain high priority to have electricity access compare to remote and undeveloped villages. Similarly, when a village obtains electricity access, more households have economic opportunity compare to villages without electricity or network connection. Families with better economic opportunity will have more capacity to pay connection and installation fee. The two problems can cause an endogeneity problem and it needs to be solved because it can cause bias on the parameter estimate.

Through the panel data analysis, the endogeneity problem can be solved with the assumption the trend from unobserved (*unobserved heterogeneity*) is fixed during the period of analysis both at household and village level. For one year period of estimation, this assumption may be hold. Thus, the Fixed-Effect Model can eliminate the unobserved heterogeneity. Equation 3 can then be rewritten as follows :

$$Y_{ij1} - Y_{ij1} = \beta^y (X_{ij1} - X_{ij0}) + \gamma^y (V_{j1} - V_{j0}) + \delta^y_h (E_{Hij1} - E_{Hij0})$$
$$+ \delta^y_k (E_{Kij1} - E_{Kij0}) + \delta^y_v (E_{Vj1} - E_{Vj0}) + \chi^y (T_1 - T_0) + (\varepsilon^y_{ij1} - \varepsilon^y_{ij0})$$

or

$$\Delta Y_{ij} = \beta^{y}\Delta X_{ij} + \gamma^{y}\Delta V_{j} + \delta_{h}^{y}\Delta E_{Hij} + \delta_{k}^{y}\Delta E_{Kij} + \delta_{v}^{y}\Delta E_{Vj} + \chi^{y}\Delta T + \Delta\varepsilon_{ij}^{y} \qquad (11)$$

Equation (11) will bring unbiased estimates if the *time-invariant heterogeneity* assumption is fulfil. However, the *time-invariant heterogeneity*, assumption may fail for several reasons. For example, the unobserved factors that affect the outcome variable of household and villages may change. For example, the timing on grid connection or installation connection may differs across villages and household. Village in remote area may have some delay on connection due to longer preparation time in transporting the equipment. Further, some households will obtain first priority for electricity connection because they have more financial capacity or they may think that after they obtain electricity their business will grow. Thus, differences in time connection and characteristics of respondents and villages may affect the dynamic of electricity connection and projection of growth. Under the time-variant heterogeneity, condition, the error structure on equation (7) can be written as follows:

$$\varepsilon_{ijt}^{y} = \mu_{jt}^{y} + \eta_{ijt}^{y} + e_{ijt}^{y} \qquad (12)$$

Thus equation (11) can be rewritten as follows:

$$\Delta Y_{ij} = \beta^{y}\Delta X_{ij} + \gamma^{y}\Delta V_{j} + \delta_{h}^{y}\Delta E_{Hij} + \delta_{k}^{y}\Delta E_{Kij} + \delta_{v}^{y}\Delta E_{Vj} + \chi^{y}\Delta T + \Delta\mu_{ij}^{y} + \Delta\eta_{ij} + \Delta e_{ij}^{y} \qquad (13)$$

where $\Delta\varepsilon_{ij}^{y} = \Delta\mu_{ij}^{y} + \Delta\eta_{ij}^{y} + \Delta e_{ij}^{y}$ will have correlation with electricity access. Under that situation, the OLS's estimate will be inconsistent. In order to measure the problem, researcher can think the correlation between unobserved heterogeneity and the initial conditions of household, village and its characteristics. The initial characteristic of village will affect the village in obtaining electricity access and those characteristics will give different responses for each household. Thus, equation 13 can be rewrite as follows:

$$\Delta Y_{ij} = \beta^{y}\Delta X_{ij} + \gamma^{y}\Delta V_{j} + \delta_{h}^{y}\Delta E_{Hij} + \delta_{k}^{y}\Delta E_{Kij} + \delta_{v}^{y}\Delta E_{Vj} + \alpha_{h}^{y}X_{ij0} + \alpha_{v}^{y}V_{j0} + \chi^{y}\Delta T + \Delta\varepsilon_{ij}^{y} \qquad (14)$$

In conclusion equation (14) will give an unbiased estimate.

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