Small area estimation with application to households with energy-saving lamps estimates in Java Island, Indonesia

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Abstract. An electricity outage hit Jakarta and some provinces on Java Island on Sunday, August 4, 2019. This blackout was the worst in many years. However, it gives positive effect that many people realize the importance of energy-saving. Since 2016, the Ministry of Energy and Mineral Resources of Indonesia has initiated the 10-percent Energy Saving National Movement in an effort to change the wasteful behavior of the Indonesian people in consuming energy. One effort to support this national movement is by using energy-saving lamps such as compact fluorescents (CFLs) and light-emitting-diodes (LEDs). CFLs and LEDs last longer and are significantly more efficient than incandescent lamps (ILs). In 2017, 92.49 percent of households in Indonesia stated that they use energy-saving lamps in their homes. However, only 70.02 percent of households stated to use energy saving lamps in all lamps installed in their homes. This indicator is calculated from the 2017 national socio economic survey-social resilience module (SSN17.HANSOS). However the SSN17.HANSOS can provide data only at the national and province levels owing to insufficient sample size. Small Area Estimation (SAE) method overcomes this problem and can produce reliable estimates for small domains. Due to the growing need for reliable and accurate estimates at district level, therefore this study aims to estimate the percentage of household that use energy-saving lamps in all lamps installed in their homes by district in Java Island using a SAE method. The result of the study can be used by local government for identifying districts in which the energy-saving programs need to be strengthened and monitoring improved.

Keywords: Small area, energy-savings, estimates

1. Introduction

Electricity is one of the main energy sources for humans. Even today, almost all human activities are supported by electricity. Accordingly it can be understood when there is no electricity, many people cannot do their daily activities. This condition was experienced by Jakarta residents recently because an electricity outage hit Jakarta and some other provinces on Java Island on Sunday, August 4, 2019. Although this electricity outage was not the first time experienced by residents of Jakarta, but many people said that the blackout was the worst in many years. However, the blackout remind many people the importance of energy-saving for a better life.

To date the Indonesian Government has not been able to fulfill the electricity needs of its population. The amount of electricity production by the State-Owned Electricity Company (PLN) is not proportional to the amount of electricity consumption needed by the community in Indonesia. In 2015 electricity
consumption in Indonesia was 232,520 MWh, while electricity produced by PLN was only 176,472 MWh [1]. Since 2016, the Ministry of Energy and Mineral Resources of Indonesia has initiated the 10-percent Energy Saving National Movement in an effort to change the wasteful behavior of the Indonesian people in consuming energy. Besides that the 10-percent Energy Saving National Movement is motivated by the rapid growth of energy consumption amid a decline in the amount of fossil energy reserves which are currently still the main source of electricity in Indonesia.

One effort that can be done to save energy is to use energy-saving lamps. This can be done by replacing incandescent lamps (ILs) with more efficient one, such as compact fluorescents (CFLs) and light-emitting-diodes (LEDs) which will help in reducing both electricity power and energy consumption. Moreover, study by Batih and Sorapipatana [2] found that the investment cost of energy saving programs is much lower than the cost for the expansion of the power supply.

It seems that Indonesian people have realized the importance of energy-saving. It is implied from BPS Statistics Indonesia (BPS) data, the percentage of households using energy saving lamps in their homes has increased from 86.26 percent in 2014 to 92.49 percent in 2017. However in 2017 only 70.02 percent of households claimed to use energy saving lamps in all lamps installed in their homes (see Figure 1). This indicator is calculated from the 2017 national socio economic survey-social resilience module (SSN17.HANSOS).

![Figure 1. The percentage of households that use energy-saving lamps in their homes, 2017](image-url)

There are growing demand for reliable small area statistics (such as district and sub district level) due to implementation of government decentralization program in Indonesia. The SSN.HANSOS can contribute partly to meet this need because the SSN.HANSOS can provide statistical data on social resilience (such as social capital, political participation, domestic violence, and pro-environmental behavior). Unfortunately, the SSN.HANSOS can provide data only at the national and province levels owing to insufficient sample size. Small Area Estimation (SAE) method overcomes this problem and can produce reliable estimates for small domains. Therefore this study aims to estimate the percentage of household that use energy-saving lamps in all lamps installed in their homes by district in Java Island using a SAE method. Java Island was selected as the study area because more than half of Indonesia's population lives on Java Island. As the 2010 Population Census results shows that there are 238.5 million people living on Java Island. It is expected that the result of the study can be used by local government
in Java Island for identifying districts in which the energy-saving programs need to be strengthened and monitoring improved.

2. Energy-saving lamps

An incandescent light lamp (see Figure 2a) glows when electricity heats wire filaments. However, these light bulbs give off more heat than light in terms of energy output. This is why the ILs are considered inefficient for the amount of electricity it drains. According to the SSN17-HANSOS, energy-saving lamps are defined as lamp that can save electricity consumption, for example energy saving lamps 5 watts of lighting produced is equivalent to 25 watts of ILs. There are two main types of energy saving lamps (see Figure 2b and 2c): i) compact fluorescents (CFLs) and ii) light-emitting-diodes (LEDs). While CFLs and LEDs last longer and are significantly more efficient compare to ILs. This type of lamp has characteristics of white light, low wattage, and the price is relatively more expensive than incandescent lamps.

![Figure 2a. Incandescent lamps (ILs)](image)

![Figure 2b. Compact Fluorescent Lamps (CFLs)](image)

![Figure 2c. Light-emitting-diodes lamps (LEDs)](image)

3. Data and Methodology

3.1. Data Source

Data source for this study is the 2017 National Socio Economic Survey-Social Resilience Module (SSN17-HANSOS). The SSN.HANSOS is conducted once in 3 years by Badan Pusat Statistik (BPS), most recently in 2017. This survey aims to provide statistical data in the areas of social resilience such as social capital, political participation, domestic violence, and pro-environmental behavior. This survey covers all districts in Indonesia. Besides the SSN17-HANSOS, this study also used the 2018 Village Potential Census (PODES18). The Village Potential Census is carried out 3 times in 10 years.

3.2. Small Area Estimation

Small Area Estimation (SAE) is one of statistical techniques for estimating subpopulation parameters whose sample size is small [3]. He defines a small area as a subset of the population with an observed variable. Hence estimation in a small area is the estimation of parameters in an area with a small number of samples (does not meet the sufficient number of samples). Estimation of small areas aims to improve the accuracy of estimators of a parameter, namely by using indirect estimation. The indirect estimation is done by borrowing strength or using additional variables in estimating parameters.

3.2.1. Basic Model of SAE

One of the basic models of SAE that is often used is the area-based model (Type A model). The area-based model is a model based on the availability of supporting data which is only available for certain area levels, for example $\mathbf{x}_i = (x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ip})^T$, that will be used to develop model $\theta_i = \mathbf{x}_i^T \beta + \mathbf{b}_i \gamma_i$.
with \( v_i \sim N(0, \sigma_v^2) \). Another model can be written in the form \( y_i = \theta + e_i \) with \( y_i \) is direct estimation vector for the \( i \)th sub-population with sampling error \( e_i \sim N(0, \sigma_e^2) \) with known \( \sigma_e^2 \). Then these two models are combined to obtain a mixed model, i.e. \( y_i = x_i^\top \beta + b_i v_i + e_i \), a special form of mixed models, which consists of fixed and random effects (called as Fay-Herriot models). If the availability of supporting data is complete up to the district level, then the SAE area can be carried out to the district level.

3.2.2. Empirical Best Linier Unbiased Prediction

The basic assumption in developing a small area estimation model is the diversity within the small area of the response variable, which can be explained by the diversity relationship corresponding to the additional information (called as fixed effect). Another assumption is the specific diversity of small areas which cannot be explained by additional information and it is the random influence of small areas. The combination of these two assumptions forms a mixed effect model.

The basic model in SAE is based on the form of a mixed linear model [3], given by:

\[
y_i = x_i^\top \beta + b_i v_i + e_i
\]

with

- \( y_i \) = Vector of direct estimation values based on survey design
- \( x_i \) = Matrix of auxiliary variable sized \( i \times j \)
- \( \beta \) = Vector of unknown fixed parameter sized \( j \times 1 \)
- \( v_i \) = Vector of small area random effect with assumption \( v_i \sim N(0, \sigma_v^2) \) and \( v_i = A \) and usually unknown
- \( e_i \) = Vector of unobserved random error with assumption \( e_i \sim N(0, \sigma_e^2) \) and \( \sigma_e^2 = D_i \) and usually it is assumed to be known

According to [3][4], estimate of Empirical Best Liner Unbiased Prediction (EBLUP) for \( \hat{\theta}_i = x_i^\top \hat{\beta} + v_i \) is of the form

\[
\hat{\theta}_i^{EBLUP} = x_i^\top \hat{\beta} + \hat{\gamma}_i (y_i - x_i^\top \hat{\beta})
\]

with

\[
\hat{\gamma}_i = \frac{\hat{A}}{A + D_i} \quad \text{and} \quad \hat{\beta} = \left( \sum_{i=1}^{m} \frac{x_i x_i^\top}{D_i + \hat{A}} \right)^{-1} \left( \sum_{i=1}^{m} \frac{x_i y_i}{D_i + \hat{A}} \right)
\]

3.2.3. Mean Squared Error of EBLUP

If \( \theta \) is a parameter and \( \hat{\theta} \) is estimate of \( \theta \), then Mean Squared Error (MSE) of \( \hat{\theta} \) can be defined as

\[
\text{MSE}[\hat{\theta}] = \text{var} [\hat{\theta}] + \left[ \text{bias} (\hat{\theta}) \right]^2; \quad \text{because} \quad 2E \left[ (\hat{\theta} - \theta)^2 \right] = 0
\]

Based on the definition of MSE, if the obtained \( \hat{\theta} \) unbiased, then MSE of \( \hat{\theta} \) will be equal to variance of \( \hat{\theta} \). While standard error of \( \hat{\theta} \) is defined as positive square root of \( \text{MSE}[\hat{\theta}] \). Prasad and Rao [5] define

\[
\text{MSE}[\hat{\theta}^{EBLUP}]
\]

is of the form
\[
MSE(\hat{\theta}_{EBLUP}) = g_{1i}(\hat{A}) + g_{2i}(\hat{A}) + 2g_{3i}(\hat{A})
\]

with
\[
g_{1i}(\hat{A}) = \frac{\widehat{AD}}{\hat{A} + D_i}, \quad g_{2i}(\hat{A}) = \left(1 - \frac{\hat{A}}{\hat{A} + D_i}\right) x_i^T \left(\frac{\hat{A} + D_i}{x_i^T x_i}\right) x_i, \quad g_{3i}(\hat{A}) = \frac{2D_i^2}{m(\hat{A} + D_i)}
\]

Steps to estimate percentage of household that use energy-saving lamps in all lamps installed in their homes by district are explained as follows:

a) Identifying households that use energy-saving lamps in all lamps installed in their homes
b) Make aggregate of households that use energy-saving lamps in all lamps installed in their homes by districts (Direct estimation)
c) Take auxiliary variables from PODES18 data which correlates with the observed variable. Originally there are 9 auxiliary variables:
   - \(X_1\) = Number of families using electricity
   - \(X_2\) = Number of junior high school
   - \(X_3\) = Number of senior high school
   - \(X_4\) = Number of education facilities
   - \(X_5\) = Number of health facilities
   - \(X_6\) = Number of health workers
   - \(X_7\) = Number of poor certificate
   - \(X_8\) = Number of villages with mobile phone
   - \(X_9\) = Number of villages using electricity
d) Select auxiliary variables using stepwise regression
e) Calculate indirect estimation using EBLUP SAE approach
f) Comparing the estimated result of Direct estimation and EBLUP SAE estimation of the percentage of household that use energy-saving lamps in all lamps installed in their homes
g) Comparing the MSE and Relative Standard Error (RSE) of Direct estimation and EBLUP SAE estimation

4. Result and Discussion
After identifying households that use energy-saving lamps in all lamps installed in their homes, then we perform direct estimation. Direct estimation only relies on information from sample. Direct estimation produces estimator with good precision when the sample size is adequate. However, when the sample size is not adequate, direct estimation results in poor precision. In this study, direct estimation of the percentage of household that use energy-saving lamps in all lamps installed in their homes is calculated for 119 districts on Java Island.

After calculating the direct estimate, then the indirect estimation is calculated using the EBLUP SAE approach to obtain the percentage of households that use energy saving lamps. Before that, the selection of auxiliary variables from PODES18 data had been done based on the correlation value and the significance of the variables studied. Utilizing the stepwise regression method, four auxiliary variables were obtained to be included in the EBLUP SAE model, they are: number of Junior high school \((X_2)\), Number of Senior high school \((X_3)\), Number of Health facilities \((X_5)\) and number of Health workers \((X_6)\). The comparison of direct estimation and EBLUP SAE estimation is presented in Figure 3. From this figure, we know that the pattern of estimation results of the EBLUP SAE approach are similar with pattern of the direct estimation results.

After estimating the percentage of households that use energy-saving lamps in all lamps installed in their homes both by direct estimation and the SAE EBLUP approach, then MSE and RSE of these two estimates are calculated. Table 1 gives descriptive statistics of RSE of direct estimation and RSE of EBLUP SAE estimation. From Table 1, it can be seen that both RSE of Direct estimation and RSE of EBLUP SAE estimation are lower than 25 percent. Moreover Table 1 shows that RSE Direct estimation...
are higher than RSE of EBLUP SAE estimation. In other words, it can be concluded that the EBLUP SAE estimation can improve the results of the direct estimation. Also Figure 4 shows that MSE of Direct estimation always higher than MSE of EBLUP SAE estimation. This indicates that the EBLUP SAE estimate is more efficient than the Direct estimate.

![Comparison of Direct Estimation and EBLUP SAE](image)

**Figure 3.** Comparison Direct Estimation and EBLUP SAE Estimation

**Table 1.** Descriptive statistics of RSE of Direct Estimation and RSE of EBLUP SAE Estimation

| Statistics            | RSE of Direct Estimation | RSE of EBLUP SAE Estimation |
|-----------------------|--------------------------|-----------------------------|
| Mean                  | 5.808472                 | 5.506361                    |
| Standard Deviation    | 2.168303                 | 1.787902                    |
| Minimum               | 1.920353                 | 1.913629                    |
| Median                | 5.295947                 | 5.127188                    |
| Maximum               | 16.10.517                | 13.02066                    |

![Comparison of MSE of Direct Estimation and MSE of EBLUP SAE Estimation](image)

**Figure 4.** Comparison of MSE of Direct Estimation and MSE of EBLUP SAE Estimation
After knowing that the estimation using the EBLUP SAE approach is more efficient, then the estimation of the percentage of households that use energy-saving lamps in all lamps installed in their homes by districts on Java Island is classified into 5 clusters using natural breaks classification. The classification result is presented in Figure 5. As is shown from this figure, majority district on Java Island are categorized in the low cluster.

Table 2. Classification result of the percentage of households that use energy-saving lamps in all lamps installed in their homes using natural breaks classification

| Cluster   | N  | Percentage |
|-----------|----|------------|
| Very low  | 12 | 10.08      |
| Low       | 32 | 26.89      |
| Moderate  | 32 | 26.05      |
| High      | 22 | 18.49      |
| Very high | 22 | 18.49      |

The top ten districts with lowest percentage of household with energy-saving lamps are Kota Sukabumi, Kabupaten Jepara, Kabupaten Indramayu, Kota Pekalongan, Kabupaten Tasikmalaya, Kabupaten Bangkalan, Kota Cirebon, Kabupaten Blora, kabupaten Kerawang and Kota Jakarta Barat. The low percentage of households with energy-saving lamps in Jakarta Barat needs special attention considering that Jakarta as the capital of the country should be a good model.

Figure 5. Thematic map of percentage of households that use energy-saving lamps in all lamps installed in their homes on Java Island, 2017
5. Conclusion and Recommendation
The results of this study reveals that based on direct and indirect estimation, the lowest percentage of households that use energy-saving lamps in all lamps installed in their homes on Java Island in 2017 is Kota Sukabumi. In addition, the results of direct estimation and estimation using the EBLUP SAE approach give similar pattern. However the estimation using the EBLUP SAE approach is more efficient for estimating percentage of households that use energy-saving lamps in all lamps installed in their homes than the Direct estimation as is indicated by both RSE and MSE of EBLUP SAE estimations are lower than RSE and MSE of Direct estimations. Therefore the EBLUP SAE approach can be useful for estimating percentage of households that use energy-saving lamps in all lamps installed in their homes. Findings of this study can be used by the local government on java Island especially in districts with low percentages to more frequently socialize energy saving programs through the use of energy-saving lamps.

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