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Environmental Performance Measurement of the Simple Urban Housing in Martubung Medan

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Abstract. In this paper, we evaluate the environmental performance of simple urban housing in Medan, Indonesia. The population in this research is the national housing Martubung. The technique of data collection used are observation, interview and documentary studies. We identify a series of quantitative and qualitative indicators and categorize them as either operational, environmental, or management indicators. We conduct co-integration analysis, correlation analysis, and multiple regression to evaluate the environmental performance of this simple housing. Based on survey and interview results undertaken in the Martubung housing in Medan, Indonesia, we performed a robust fitting of various factors. By calculating their performances based on the results of the integral indicators, we defined coefficients that reveal the level of environmental performance in the region. We found the most important factor impacting the environmental performance of housing to be ease of access, followed by the existence of adequate public transport, sewage systems, and road maintenance in residential areas. The perception of the environmental performance of housing is to some extent dependent on the local residents. The diverse and complex relationships between the identified indicators are consistent with the observations made during the environmental performance assessment.

1. Introduction
The establishment of an environmental management system (EMS) has recently been advocated for most economic sectors. An EMS can provide a framework for achieving and demonstrating a desired level of environmental performance [1,2]. Quantitative environmental information is a significant component of any EMS for describing and assessing ongoing improvements. In implementing an EMS, the identification of environmental performance indicators represents one means for conducting internal evaluations and for communicating with external stakeholders [3,4]. The environmental performance of simple housing developments, which can be defined as the residential management’s success in managing the interaction between resident activities and the environment, plays an important role in environmental protection. The environmental performance assessment (EPA) is a critical EMS tool for checking, reviewing, monitoring and evaluating the environmental performance of organizations. It involves an ongoing process of collecting and assessing data to evaluate performance and trends over time [5,6]. A primary role of the EPA is to provide a comprehensive assessment of the environmental performance of simple housing management. Environmental indicators focus on the use of tangible measures to evaluate environmental performance, based on significant and standardized data, not only for the purposes of assessment but also for comparison of different site conditions [7]. These indicators can highlight any adverse trends in the environmental control process and by monitoring them regular
evaluation and target control can be performed [6]. Since operational performance is an important and indispensable element in evaluations of environmental performance, in this paper we focus on EPA evaluation factors at the operational level because site assessment is essential for all parties in a region.

We use environmental operational indicators (EOIs) as input organizational performance measures and environmental performance indicators (EPIs) as output housing performance measures. In the following, we specify the EOIs and EPIs we used in this study.

In Indonesia, urban residential hazards are caused not only by one-off events like earthquakes, landslides, or cyclones, but also by physical changes from housing restoration, renovation, or reconstruction activities. As a case study, we used the Griya Martubung I Housing in Medan, where the residents’ livelihoods rely on every available resource in and around the housing area. In the Martubung simple housing, the CO2 emissions caused by housing renovations accounts for most of the environmental burden [8]. The production of CO2 emissions into the air is associated with the complex interaction between housing alterations, the dynamics of residential life, and the attendant physical changes, which are concurrent with the ongoing increase in infrastructure demand due to population growth and urban housing development.

We conducted qualitative and quantitative research to gain knowledge about various components of the environment, social facilities, and activities of residents related to household waste and the generation of CO2 emissions. We investigated each component by conducting in-depth interviews, making observations, and holding discussions with various stakeholders. From our analysis of the components, we found the generation of household waste and CO2 emissions to be influenced by the interactions between various components of the residential environmental system. The linkages between these various system components play direct and indirect roles in the production of water pollution and CO2 emissions, as can be seen in the activities related to space utilization as well as the regulations related to housing development and residential life in Martubung, Medan.

2. Research objectives
In this study, our goal was to evaluate the environmental performance of simple housing by correlating the operational, management, and environmental indicators as input factors of the EOIs with the residents’ assessments and levels of satisfaction as output factors of the EPIs for simple housing in Martubung Medan, Indonesia. We identified a series of quantitative and qualitative indicators and categorized them as either operational, environmental, or management indicators [7]. We then applied co-integration analysis, correlation analysis, and multiple regression to evaluate the environmental performance of the simple housing. Our specific objectives were as follows:

- Highlight the importance of the EPA in evaluating environmental performance;
- Identify a series of input (EOIs) and output (EPIs) assessment indicators;
- Examine the relationships between the EOIs and EPIs in the context of simple housing by the use of robust fitting methods;
- Provide recommendations for simple housing management.

3. Methods
We adopted the Eco informatics tools and techniques associated with each step of the data life cycle in [9] with some modifications in consideration of the residential conditions of the Martubung simple housing complex [10,3]. We used robust fitting methods to correlate the EOIs and EPIs, and our work was supported by the SPSS and Math lab programming package, including all diagrams and mathematical equations.

4. Development of performance indicators
The basic principles for developing indicators include the use of existing data, re-evaluating underlying assumptions, integrating a long-term focus with short-term change, relating indicators to individual and vested stakeholders, identifying the direction of sustainability, presenting indicators as a whole system, and determining linkages. Using a simple and easy to understand format for presenting data is also critical so that decision makers and other stakeholders can use existing data to seek further information that addresses issues of primary community concern. The ecological indicator is a measure, or a collection of measures, that describes the condition of an ecosystem or one of its critical components. Ecological indicators are used to communicate information about ecosystems and the impact of human activity on ecosystems to groups such as the public or government policy makers.
Table 1. Environmental performance indicators (ISO 14031) and data collection methods [11]

| Indicator          | Sub Indicator          | Indicator component                        | Type          | Methods                  |
|--------------------|------------------------|--------------------------------------------|---------------|--------------------------|
| Management         | Training               | Benefit for residents                      | Qualitative   | Observation, Interview   |
|                    | Government Regulation  | Compliance                                 | Qualitative   |                          |
|                    | Social Quality         | Social relations between residents         | Qualitative   |                          |
|                    | Facilities             | Infrastructure                             | Qualitative   |                          |
|                    |                        | Public and Social Facilities               | Qualitative   |                          |
| Development        | Repair on damaged facilities | Qualitative                                   | Qualitative   |                          |
|                    | Temporary garbage disposal | Qualitative                                  | Qualitative   |                          |
|                    | Control system on waste water | Qualitative                                  | Qualitative   |                          |
|                    | Pedestrian             | Qualitative                                 | Qualitative   |                          |
|                    | Sanitation             | Qualitative                                 | Qualitative   |                          |
|                    | Green open space       | Qualitative                                 | Qualitative   |                          |
|                    | Accessibility          | Qualitative                                 | Qualitative   |                          |
|                    | Drainage               | Qualitative                                 | Qualitative   |                          |
|                    | Infrastructure         | Qualitative                                 | Qualitative   |                          |
|                    | Street lighting        | Qualitative                                 | Qualitative   |                          |
|                    | Security               | Qualitative                                 | Qualitative   |                          |
|                    | Garbage disposals system | Qualitative                               | Qualitative   |                          |
| Environmental      | Distance from          | The impact of the location proximity to     | Qualitative   | Observation, Interview   |
| (External)         | Industrial Actives     | industrial activities                       |               |                          |
|                    | Security               | Security System                             | Qualitative   |                          |
| Operational        | Electrical Energy      | Monthly electricity consumption             | Quantitative  | Observation, Interview   |
|                    | Consumption            |                                           |               |                          |
|                    | Water Consumption      | Monthly water consumption                   | Quantitative  |                          |
|                    | CO2 emission           | The number of motor vehicles owned per house| Quantitative  |                          |
|                    |                        | Volume of daily domestic garbage            | Quantitative  |                          |

The EPI framework can be divided into three categories:

a. Environmental operational indicators (EOIs): indicators that measure the environmental burden caused by the activities of residents. **EOIs** are used to assess the major inputs, including resources, energy, and other aspects of existing facilities.

b. Environmental management indicators: indicators that measure the methods used by organizations that manage and operate resources for residents’ activities as contributions to residential life. These aspects can be measured both qualitatively and quantitatively.

c. Management-related indicators: considered to be environmental performance indicators because they are needed for calculating energy or material efficiency and to reduce the environmental burden per unit of economic activity in order to realize a sustainable society.

Organizational operations are defined as the physical facilities and equipment used during production processes [5,6]. We performed data collection by observation, interviews, questionnaires, and for some indicators, photographs of the location.

5. Results and discussion

This study focused on the activities of 1567 residents in 12 neighborhood clusters. The research results are based on surveys and questionnaires of the residents and 12 chiefs of each neighborhood cluster and three heads of each sub-district. There were a total of 144 randomly chosen residents involved in the research process.
Samples were randomly selected from each block, with as many as 12 inhabitants of the 12 houses on each block. Of the 144 respondents, two of the questionnaires submitted were not valid, so the number of completed questionnaires was 142. The types of questions in the questionnaire included the residents’ attributes, their environmental performance attributes, residential services and utilities, water and energy consumption, and household waste. The urban simple housing of Martubung is good-quality simple housing built by the local government. Of the total area, 50% is allocated for housing and the rest is allocated for commercial, social, and public facilities, roads and canals, green open spaces, and a pond. Table 2 shows the Martubung land use distribution:

| Land Use           | Area (m²) | %  |
|--------------------|-----------|----|
| Housing            | 533.708   | 50 |
| Commercial         | 111.920   | 11 |
| Social Facilities  | 36.399    | 4  |
| Road and canal     | 257.037   | 24 |
| Green Open Space   | 35.735    | 3  |
| Pond               | 88.300    | 8  |
| **TOTAL**          | **1,063.099** | **100** |

The quantitative environmental indicators we identified include the residents’ attributes, house attributes, type and volume of energy consumption, and utilities and services, as listed in Table 3.

| No  | Quantitative Indicator        | Sub indicator                                      |
|-----|-------------------------------|----------------------------------------------------|
| IK1 | Residents’ attributes         | Location / Block, Occupation, Education, Monthly Income, Own Vehicle |
| IK2 | House attributes              | House status, Function of house, House Type       |
| IK3 | Volume of energy consumption  | Clean water resource, Electricity, Air Condition, Energy resource for cooking (gas or electricity) |
| IK4 | Utilities and Services        | Waste Water treatment, Temporary Household or Domestic Landfills |

Table 3. Quantitative environmental indicators of Martubung housing
The diagrams in Fig. 3 show profiles of the residents of Martubung simple housing in Medan, North Sumatera.

Figure 3a. Occupation

Figure 3b. Residents’ average monthly income

Figure 3c. Education level

Figure 3d. House ownership status

We assessed the performance of the qualitative indicators, as listed in Table 4, through observation, interviews with the residents, disseminating questionnaires, and taking photos in some cases, i.e., road conditions, street lighting, pond, sanitation, landfills, green open space, drainage, pedestrian areas, and sanitation.

Table 4. Qualitative environmental indicators in Martubung

| No.  | Indicator                  | No.  | Indicator                                    |
|------|----------------------------|------|----------------------------------------------|
| EPI 1| Green Open Space           | EPI 9| Landfills                                   |
| EPI 2| Distance from Industrial Activities | EPI 10| Security                                   |
| EPI 3| Drainage                   | EPI 11| Sanitation                                  |
| EPI 4| Accessibility              | EPI 12| The role of manager                         |
| EPI 5| Road conditions            | EPI 13| Residents’ participation                    |
| EPI 6| Pedestrian areas           | EPI 14| Quality of space                            |
| EPI 7| Street Lighting            | EPI 15| Social Quality: relations between residents |
| EPI 8| Pond                       |      |                                              |

We used the Likert scale to measure the residents’ assessment and perceptions of these indicators, as shown in Figure 4 below.
To evaluate the impact of the quantitative and qualitative EPIs on the simple housing environment, the use of correlation analysis is effective for evaluating their mutual influences. Let us suppose that $x_i$, $i = 1, 2, \ldots, n$ are the quantitative indicators and $y_j$, $j = 1, \ldots, m$ are the qualitative indicators. All vectors are confined within some closed arbitrary boundary.

In addition, the input data have a set of autocorrelation relationships. We note that some coefficients in the matrix of pair correlations are linearly dependent. As such, the determinant of the matrix is equal to zero. Thus, it is necessary to reject input data for pair correlation parameters $k > \pm 0.7$ for groups of variables $x_i$ and $y_j$, which are the correlation matrices elements $K = \| k_{x_i y_j} \|$:

$$
k_{x_p x_q} = \text{cov}(x_p, x_q) / (D[x_p^2] \times D[x_q^2])
$$

where $\text{cov}(x_p, x_q)$ is the covariance between the sets of variables $cov \ x_p, x_q$ and $D[x_p^2], D[x_q^2]$ is the variance of the variables.

Several methods can be used to predict environmental performance as well as to investigate the influencing factors. One such method is regression analysis, which is a statistical technique for investigating and modeling the relationships between variables where the variables are not independent. To define the influence coefficient, we applied multiple regression. We also defined the quantitative and qualitative management-oriented indicators in the region. If $Y$ is the dependent variable and $X_1, X_2, \ldots, X_k$ are independent variables, then generally their linear regression can be expressed as $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon$, where $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ are the regression parameters and $\varepsilon$ is the error of the normal distribution, with the mean equal to zero and with equal variance. The problem in regression analysis is in determining the best estimator for $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$, whose values are strongly influenced by the methods used. To overcome these problems, a robust parameter estimation method is required. The robust fitting method uses an iteratively re-weighted least-squares algorithm, with the weights at each iteration calculated by applying the bi-square function of the residuals from the previous iteration.

The estimation principle is to minimize the residual function. In this research, not all factors that affect the performance of the environment exist in each cluster. Therefore, we discuss the linear regression model and the environmental performance value $Y$ of all the simple

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{example.png}
\caption{Residents’ assessments of environmental performance of Martubung housing}
\end{figure}
Martubung housing clusters, based on the residential electricity consumption ($X_1$) and water consumption ($X_2$). Further weighting is performed as follows:

Table 5. Further weighting

| Parameter | Ranking | Aspect          | Ranking |
|-----------|---------|-----------------|---------|
| $P_1$     | 2       | Main competence (w3) | 3       |
| $P_2$     | 1       | Supporting competence (w2) | 2       |
| $P_{..n}$ | 3       | Performance (w1)     | 1       |

Weighting formula:

$$W_j = \frac{(n-r_j+1)}{\sum(n-r_p+1)}$$

- $w_j$ = the normal weight for a parameter - j (j = 1,2,3,…n)
- $n$ = the number of parameters being examined.
- $r_j$ = ranking position of a parameter.
- $r_p$ = parameter (1,2,3,…n)

Weight calculation:

- Weight of parameter -1: $W_1 = (3-2+1) / \{ (3-3+1) + (3-2+1) + (3-1+1) \} = 0.33$
- Weight of parameter -2: $W_2 = 0.17$; and weight of parameter - 3: $W_3 = 0.50$

$$Y = \sum_{i=1}^{n} \sum_{j=1}^{m} W_{ij} X_{ij}$$

We used data intervals, so the quantitative analysis comprises parametric statistics based on the data to be analyzed [12,13].

For our regression model, we used the least squares method as follows:

$$\hat{Y}_1 = -18 + 0.45 X_1 + 1.32 X_2 + 0.37 X_3 + 0.81 X_4 + 0.38 X_5$$

$R^2 = 99.7\%$, $R^2$ (adj) = 99.5\% and $s = 4.05$

We conducted a classic assumption test to determine if the linear regression assumption of Eq. (5) was fulfilled or not. These results and those of normality, homokedastisitas, and non-autocorrelation tests show that none of the three assumption were fulfilled. The only fulfilled assumption was that of non-multicollinearity, and we found outliers in numbers 11, 24, 35, and 47. The results show that $F = 11.77$ with $p = 0 < 5\%$, which confirms the effectiveness of the linear regression model Y with $X_1$, $X_2$, $X_3$, $X_4$, and $X_5$. Hence, since there are outliers, we performed estimation using robust linear regression with M-, S-, and MM-estimations.

5.1. Regression model by M-estimation

The environmental performance regression model by M-estimation is given by:

$$Y = +38 + 0.46 X_1 + 0.34 X_2 + 0.4 X_3 + 0.16 X_4 + 0.21 X_5$$

with $R^2 = 100\%$, $R^2$ (adj) = 100\% and $s = 10.63$.

We obtained the regression model shown in Eq. (6) after 50 iterations. This model shows that by increasing the accessibility score by one, the green open space score by one, the temporary landfills score by one, and the public and social facility score by one, the environmental performance score will
increase by 0.93. Model (6) has two outliers—data numbers 7 and 14. We performed the next test to determine if accessibility, open green space, temporary landfills, a pond, and social facilities had a significant influence on environmental performance.

5.2. Regression model with S-estimation
The results of the partial independent variable test on the regression model with S-estimation are given by:
\[
Y = -57 + 0.43 X_1 + 0.64 X_2 + 0.17 X_3 + 0.04 X_4 + 0.18 X_5
\] (7)
with \(R^2 = 99.9\%\), \(R^2(\text{adj}) = 99.9\%\) and \(s = 8.345\).

Regression model (7) shows that for every increase of one in the environmental performance score, the accessibility score will increase by 0.43, the open green space score will increase by 0.64, the pond score will increase by 0.04, and the public facilities score will increase by 0.18. Model (7) has no outliers. We performed the next test to determine if the accessibility, open green space, temporary landfills, a pond, and social facilities had a significant influence on environmental performance in the Martubung simple housing region.

5.3. Regression model with MM-estimation
The regression model with MM-estimation is given by the following:
\[
Y = 21 + 0.43 X_1 + 0.62 X_2 + 0.119 X_3 + 0.74 X_4 + 0.38 X_5
\] (8)
with \(R^2 = 99.6\%\), \(R^2(\text{adj}) = 99.5\%\) and \(s = 7.55\).

The results show that Regression model (8) has no outliers. We performed the next test to determine if accessibility, open green space, temporary landfills, a pond, and social and public facilities had a significant influence on environmental performance.

The results of the partial independent variable test on environmental performance prediction with M-estimation shows that accessibility and open green space significantly influence environmental performance, while temporary landfills and a pond have no significant effect on environmental performance. The partial independent variable test on environmental performance prediction with S-estimation shows that the four independent variables i.e., accessibility, open green space, a pond, and public and social facilities had a significant influence, while landfills had no significant influence on environmental performance in the Martubung simple housing. The partial independent variable test on environmental performance prediction with MM-estimation shows that, of the independent variables, only accessibility significantly influenced the environmental performance of Martubung simple housing.

Next, we developed an optimal model of the above regression model by establishing criteria for determining the best regression model, e.g., determination coefficient \(R^2\) or \(R^2(\text{adj})\) and standard deviation \(s\). The best model is that with the biggest \(R^2\) or \(R^2(\text{adj})\) and the smallest standard deviation \(s\). The results show that only the accessibility variable has a significant influence on environmental performance of the Martubung simple housing, while the other independent variables do not. We found no outliers.

| Table 6. \(R^2\) or \(R^2(\text{adj})\), s, significant variables and outliers for Regression models (5) – (7) |
|-------------------------------------------------|-------|-------|-------|
| Estimation | M     | S     | MM    |
| Model      | (5)   | (6)   | (7)   |
| \(R^2\)    | 100%  | 99.9% | 99.6% |
| \(R^2(\text{adj})\) | 100%  | 99.9% | 99.5% |
| \(s\)      | 10.63 | 8.345 | 7.55  |
| Significant variables | \(X_1, X_4\) | \(X_1, X_3, X_4\) | \(X_1\) |
| Outliers   | 7:14  | -     | -     |

The environmental model with S-estimation with significant independent variables is given by:
\[
\hat{Y} = -18 + 0.45 X_1 + 1.32 X_2 + 0.37 X_3 + 0.81 X_4 + 0.38 X_5
\] (9)
with \(R^2 = 99.7\%\), \(R^2(\text{adj}) = 99.5\%\) and \(s = 4.05\)

and:
\[
Y = -57 + 0.43 X_1 + 0.64 X_2 + 0.17 X_3 + 0.04 X_4 + 0.18 X_5
\] (10)
with \(R^2 = 99.9\%\), \(R^2(\text{adj}) = 99.9\%\) and \(s = 8.345\)
These results show that $R^2$ (adj) = 99.9% which means that 99.9% of $Y$ is influenced by $X_1$, $X_3$, $X_4$, while only 0.1% is influenced by other variables.

The significance test on the above model yields $F = 465.7$ with $p = 0$ which is < 5%, hence the model is good. Table 7 show the partial test results in which all the independent variables for Regression model (10) are significant.

| Coefficient | t    | p     | Conclusion |
|-------------|------|-------|------------|
| Constant    | -50  | -5.5  | 0.000      | Significant |
| $X_1$       | 0.43 | 12.766| 0.000      | Significant |
| $X_3$       | 0.62 | 0.59  | 0.000      | Significant |
| $X_4$       | 0.74 | 0.228 | 0.011      | Significant |
| $X_5$       | 0.38 | 0.281 | 0.012      | Significant |

Based on the above results, landfills have no significant effect on the environmental performance. This might be because, among other reasons, the landfills are located quite far away from the 11 blocks of housing, and so do not disturb the comfort of the residents. Also, the landfills are located by the pond and all household garbage stored in the temporary landfills is regularly removed from the housing area by a janitor. With regard to the pond, it was initially created by accident after soil dredging. In 2011, the pond was clean and residents with children could play in the adjacent area [8]. Today, however, the entire surface of the pond is covered by the water hyacinth plant. This shows that one of the indicator variables for improving environmental performance is not well maintained.

The above results show that the dominant indicator that affects the environmental performance of Martubung simple housing is accessibility. Increased accessibility reduces the need for motor vehicle ownership, thus reducing CO$_2$ emissions. We also consider accessibility to increase the convenience of residents in conducting their domestic tasks and in facilitating mobility in the community, which may increase economic activity and wealth. Overall, improving the quality of services and accessibility can improve the environmental performance in Martubung simple housing. Results from the Likert scale comparing the perceptions of residents regarding the operational indicators indicate that accessibility has the lowest satisfaction score, followed by landfills and security.

Figure 5. Residents’ perception about environmental performance of Martubung housing

All things considered, according to the results of the most fitted mathematical methods for evaluating the performance of urban simple housing in Medan, Indonesia, key factors that significantly impact the simple housing’s reputation include the quality of the simple housing management system, the competence level of top management, and management practices in relation to the housing residents.

Physically, we could evaluate the environmental performance by comparing the environmental performance index scores over the assessment period. However, there has been no ongoing assessment
of the environmental performance of Martubung simple housing and no measurement system has been established. Meanwhile, the assessments and perceptions of the residents could be used as a control variable in the environmental performance of the region, since the residents’ satisfaction level is linearly correlated with the environmental performance of the area in which they live. Based on our site survey and data analysis, the majority of residents want ease of access in reaching their target destinations to improve mobility within and outside the region. In other words, they want improvements in mass public transportation in order to avoid having to buy a motor vehicle. This sentiment may differ from residents in elite housing or estates where the priority of the residents is security and they are disinclined to allow public transport or outsiders to enter their region. Therefore, environmental performance of housing is to some extent dependent on the local residents.

6. Conclusion
Measurement of the environmental performance of urban simple housing in Medan, Indonesia can be based on choice of pathways in its symbiotic structure.

The environmental performance of housing is to some extent dependent on the local residents. Relationships between identified diverse and complex indicators are consistent with observed behavior during the environmental performance assessment. Theoretically, community ecology studies can provide a much needed resource even when it does not provide definitive answers about what to do in particular cases but only explores the possibilities. There are a variety of evaluation concepts available that are related to performance measurement. Cause–effect analysis is another alternative for improving the management, control, and risk reporting of environmental performance.

Although this paper has described a fairly linear process for calculating indicators and weighting and estimating performance, in practice, evaluation is more iterative and may involve a process of multiple revisited steps. It may be necessary to adjust targets after the calculation of the initial indicators, particularly if the distribution of the indicator scores seems inaccurate. It may also be helpful to involve experts during various stages of the calculation process to vet the quality and veracity of each indicator. Ultimately, for the purposes of future research, it is essential to properly record all steps taken in calculating scores in order to ensure transparency regarding each developmental step.

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