

Clustering Batik SMEs: Open Innovation for Environmental Sustainability [†]

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Abstract: Environmental sustainability is challenging for SMEs, mainly due to SMEs' limited resources. To achieve environmental sustainability, SMEs must innovate their production process and waste management. SMEs can utilize open innovation to counter their limited resources problem. This study aims to explore the clustering of SMEs based on their environmental sustainability achievement and the utilization of open innovation to achieve it. The data used in this study are from 38 SMEs that produce Batik and are located in Rembang Regency, Indonesia. The clustering process is performed using the K-Means algorithm. The results show that the data are grouped into two clusters. The first cluster, with 26 entities, tends to have higher environmental sustainability achievement and open innovation involvement than the second cluster with 12 entities. Therefore, the second cluster needs more attention from external stakeholders to encourage and support them in achieving environmental sustainability, primarily related to using environmentally friendly materials in production.



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1. Introduction

Sustainability is a concept that seeks to balance three main dimensions, known as the triple bottom line: economic, environmental, and social [1–4]. In the economic dimension, sustainability emphasizes the importance of sustainable financial growth and profits, where companies and organizations need to ensure the continuity of their business by remaining profitable in the long term [3–5]. The environmental dimension includes efforts to reduce negative impacts on nature, including efficient use of natural resources, reduction in greenhouse gas emissions, proper waste management, and protection of ecosystems [3,6]. Meanwhile, the social dimension focuses on the welfare of society by ensuring that business activities not only benefit capital owners but also provide benefits to employees, local communities, and the wider community [2,7]. The implementation of sustainability by SMEs is critical because SMEs play a vital role in the global and local economy [7]. Sustainability helps SMEs balance economic growth, environmental preservation, and social welfare, known as the triple bottom line.

Batik SMEs face significant challenges in integrating sustainable practices into their production processes [8,9]. These challenges include the over-utilization of resources, polluting production waste, and difficulties in adopting environmentally friendly technologies [8,9].

Limitations in financial resources, access to cutting-edge technology, and knowledge of best practices are some of the main obstacles [8]. Research by Gunawan et al. [8] found that Batik SMEs face significant challenges in adopting sustainable practices. The main obstacles identified were limited financial resources for investment in environmentally friendly technologies, a lack of knowledge and awareness of sustainable practices, and resistance to change from traditional, long-standing production methods [8]. The study by Phang et al. [10] also showed that one of the main obstacles was the lack of training and education on sustainable practices. However, with the global push and regulations to implement sustainability principles, Batik SMEs are now required to increase their commitment to the environment and social responsibility. In addition, Batik SMEs do not yet understand the extent to which they have implemented sustainable practices and how their performance compares to industry standards or their competitors [9]. This uncertainty is often caused by the lack of precise evaluation tools and metrics to measure the effectiveness of their sustainability initiatives [8,9]. Batik SMEs often have limitations in accessing or adopting new technologies and practices that can improve sustainability. Many Batik SMEs do not have adequate information on collaborating with external partners, such as research institutions, government agencies, or technology companies, to leverage new ideas and technologies to improve their production processes and reduce environmental impacts.

One of the factors is a solution to achieving organizational sustainability through the application of the open innovation (OI) concept [3,5], where Batik SMEs can collaborate with various parties, including the government, academics, and the private sector to develop and adopt best practices in sustainability [3,11,12]. Supporting factors in the application of open innovation include the availability of technology, willingness to collaborate, and policy support from the government. OI is crucial in helping SMEs achieve sustainability by enabling them to access the latest knowledge and technology from external sources [12]. Through collaboration with universities, research institutions, and industry partners, SMEs can adopt innovative solutions that reduce environmental impacts and improve operational efficiency [12,13]. This approach not only reduces costs and risks associated with internal development but also improves the competitiveness and reputation of SMEs in the market [13]. Therefore, this study aims to map Batik SMEs based on sustainable performance and the application of OI using the K-Means clustering algorithm. In addition, the focus of this study is to identify patterns and segmentation among Batik SMEs in terms of sustainability practices and OI, as well as evaluate the impact of adopting environmentally friendly technologies.

This study offers significant novelty by integrating the mapping analysis of Batik SMEs based on sustainability aspects and OI implementation using the K-Means clustering method. As opposed to previous studies, which often focus on sustainability or innovativeness aspects separately, this study combines both dimensions to provide a more comprehensive insight into the position of Batik SMEs in the context of both issues. Applying the K-Means clustering algorithm identifies patterns and segmentation in sustainability and OI practices in Batik SMEs and clarifies how each unit adopts environmentally friendly technologies and practices. This approach provides a more in-depth assessment of the effectiveness of sustainability and innovation strategies in the batik sector. It provides practical guidance for industry players to improve their performance through external collaboration and the application of new technologies. In addition, this study can be used as a strategic recommendation for Batik SMEs to improve their sustainability performance by utilizing ideas and technologies from external sources.

2. Methodology

This research was carried out by implementing several main steps, namely, determining variables, data collection, and cluster development. These steps can be seen in detail in the following sub-chapters.

2.1. Data and Samples

This study uses the theory of unsupervised learning, namely, clustering. To create a cluster, the data to be processed are first acquired primarily. Data acquisition was carried out by recapping the results of the questionnaire answers that had been distributed to several SMEs that had been designated as respondents. The number of SMEs that have been designated as respondents is 38 Batik SMEs in Rembang Regency. Respondents in this study vary in age, ranging from SMEs that have been running for 8 years to 110 years. Each business unit answered several statements related to the topic of waste management in the production process of batik making in the research area.

2.2. Variables

The statements answered by the respondents were categorized based on several variables. Each variable has a meaning related to the topic of batik waste management, especially how respondents efficiently use natural resources, use environmentally friendly materials, and manage waste when carrying out the production process. Here are some of the attributes that are used as the basis for questions in the questionnaire.

- a. The X1 column corresponds to the statement of the condition of the SME unit regarding the material used efficiently in the entire production process (e.g., fabrics, dyes, waxes).
- b. The X2 column relates to the statement of the condition of the SME unit regarding the materials used in the entire production process that do not harm the environment (e.g., fabrics, dyes, waxes).
- c. The X3 column relates to the statement of the condition of the SME unit regarding the efficient use of energy in the entire production process (e.g., the use of electric canting, which is more economical compared to kerosene stoves).
- d. The X4 column relates to the statement of the condition of the SME unit regarding the efficient use of water in the entire production process (e.g., the reuse of wastewater that has been refiltered).
- e. The X5 column relates to the statement of the condition of the SME unit regarding the organization's production waste having a negative impact on the environment (for example, liquid waste from the nglorot or dyeing process).
- f. The X6 column relates to the statement of the condition of the SME unit regarding external partners giving ideas for waste treatment innovations in the production process.
- g. The X7 column relates to the statement of the condition of the SME unit regarding external partners, with the organization designing waste treatment innovations in the production process.
- h. The X8 column relates to the statement of the condition of the SME unit regarding the organization utilizing new technology from external partners for waste treatment innovation in the production process.

The SME answer is divided into 7 answer scales; the greater the answer value, the more the SME agrees with the statement on the questionnaire. A value of 1 indicates the highest level of disapproval, a value of 4 indicates a neutral level of statements, and a value of 7 indicates the highest level of approval.

2.3. Cluster Development

The development of clusters is based on respondents' answers, which are carried out in several stages. The clusters formed are made based on the K-Means clustering method [14].

a. Exploring Data Frames

The exploration of data frames in this study was carried out by searching for missing values and outliers in the data. A missing value search can be realized using the `isnull` or `isna` function, a function on Pandas 2.0.3 as one of the Python Library in Google Colab to look for parts of data that are empty or have no value. Outlier detection is performed using a boxplot.

b. Data Preprocessing

Data preprocessing is a stage in cluster creation that is carried out to prepare data so that they can be processed at the time of cluster creation. This stage is carried out by normalizing the data to equalize the units of measurement from the data owned. So, the results of the cluster can be more representative and accurate. In this study, normalization uses Standard Normal Transformation (Z-Transformation).

c. Model Tuning

The tuning model is the stage of determining the most optimal cluster value in the cluster division. This stage is carried out by building a graph of the elbow method. The K value, which will later be the starting point for the sway of the graph, will be a marker of the optimal number of cluster creation for the dataset.

d. Model Building

This stage is the stage of the cluster division based on datasets. This cluster division will later follow the principle of K-Means clustering, whose K value has been determined based on the tuning model in the previous stage.

e. Model Visualization

The visualization stage is carried out by mapping the results of the division of clusters into Cartesian fields. This mapping uses the Principal Component Analysis (PCA) dimension reduction technique as a method of changing the number of variables from more than two dimensions into two dimensions.

3. Results and Discussion

3.1. Data Frame Exploration

Dataframe exploration is carried out by searching for missing values and outliers.

a. Missing Value

The missing value is searched using the `isnull` function. Based on the test, it was found that there is one missing value from the X1 column. To fill in the data, an average value search was carried out from the X1 column. The average value obtained is 4.97297, and the result can be rounded to number 5. Thus, the missing value row in the X1 column can be filled with the number 5.

b. Outlier

The outlier search is performed using a boxplot, and presented in Figure 1. The result obtained is in the form of an outlier in X3, but because compared to other columns this outlier value does not show a value that exceeds the maximum value in other columns, the outlier value can be ignored.

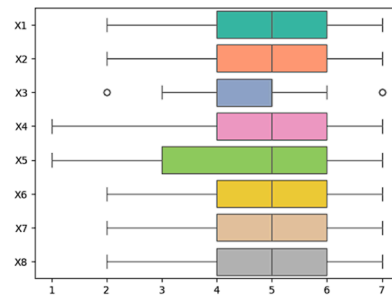


Figure 1. Outlier search results.

3.2. Data Preprocessing

Data preprocessing is carried out by normalizing with Z-Transformation of the data that has been input in the previous process. Normalization was carried out by changing the initial scale to a value in the range of -1 to 1 . The results of the normalization is shown in Figure 2.

	X1	X2	X3	X4	X5	X6	X7	X8
0	0.853288	0.752583	1.734623	0.175574	0.312207	0.950019	1.602566	1.105934
1	0.853288	1.374282	0.269830	0.842754	1.630412	1.644264	0.080128	1.105934
2	1.684696	0.752583	0.269830	0.842754	0.971309	0.950019	1.602566	1.105934
3	1.684696	0.752583	0.269830	0.842754	0.971309	0.950019	0.841347	1.105934
4	0.021879	1.374282	1.734623	1.509934	0.971309	0.950019	1.602566	1.856388
5	0.021879	1.374282	1.734623	1.509934	0.971309	0.255774	0.841347	0.355479
6	0.853288	0.752583	0.269830	0.842754	0.312207	0.950019	0.841347	-0.394976
7	0.021879	0.752583	0.269830	-0.491606	0.971309	0.950019	0.841347	1.105934
8	0.021879	0.130884	0.269830	-0.491606	0.312207	0.255774	-0.681091	0.355479
9	0.853288	0.130884	0.269830	0.842754	0.312207	0.950019	0.080128	0.355479
10	0.853288	0.130884	-0.462566	0.175574	0.971309	0.255774	0.080128	1.105934
11	0.021879	0.752583	0.269830	0.842754	0.312207	-0.438470	0.080128	-0.394976
12	0.021879	0.752583	0.269830	-0.491606	0.312207	0.255774	0.841347	0.355479
13	0.853288	0.130884	0.269830	0.842754	0.312207	0.255774	0.080128	1.105934
14	0.853288	0.752583	1.002226	0.842754	0.971309	1.644264	0.841347	1.105934
15	0.021879	0.130884	1.002226	0.842754	1.630412	0.950019	0.841347	1.105934
16	-0.809529	-1.734213	-0.462566	-1.825967	-1.665102	-1.826960	-1.442310	-1.145431
17	-1.640938	-1.112514	-1.194962	0.842754	-1.005999	-0.438470	0.080128	-0.394976
18	0.021879	-1.112514	0.269830	-0.491606	-1.005999	-0.438470	-1.442310	0.355479
19	-0.809529	-1.112514	-1.194962	0.175574	0.312207	-0.438470	-0.681091	-1.895886
20	-2.472346	-1.734213	-1.927358	-1.825967	-1.665102	-1.826960	-1.442310	-1.895886
21	-0.809529	-1.734213	0.269830	-1.158787	-1.005999	-1.826960	-0.681091	-1.145431
22	-0.809529	0.130884	0.269830	-0.491606	0.312207	-0.438470	0.080128	0.355479
23	-0.809529	-1.734213	-1.194962	0.175574	-1.005999	-1.826960	-2.203528	-1.895886
24	0.853288	0.130884	-1.927358	-1.825967	0.312207	0.255774	0.841347	0.355479
25	0.853288	0.752583	-1.194962	-2.493147	0.971309	0.950019	0.841347	-0.394976
26	-2.472346	-1.734213	-1.927358	-1.825967	-1.665102	-1.132715	-1.442310	-1.145431
27	0.021879	-0.490815	-0.462566	-0.491606	-2.324204	-1.132715	-2.203528	-1.895886
28	0.021879	-0.490815	0.269830	0.175574	0.312207	-1.132715	0.080128	-0.394976
29	-0.809529	-0.490815	-1.194962	0.175574	-0.346896	-1.132715	-0.681091	-0.394976
30	0.021879	-0.490815	-1.194962	-0.491606	0.312207	-1.132715	-0.681091	-1.145431
31	-1.640938	-1.734213	-0.462566	0.175574	-1.005999	-0.438470	-0.681091	-0.394976
32	0.853288	1.374282	-0.462566	-0.491606	-0.346896	0.950019	0.841347	0.355479
33	0.021879	1.374282	1.002226	0.842754	-0.346896	0.950019	0.841347	-0.394976
34	-0.809529	0.130884	1.002226	0.175574	0.971309	-0.438470	-0.681091	-0.394976
35	0.021879	0.130884	0.269830	-0.491606	0.312207	-0.438470	0.841347	1.105934
36	1.684696	0.752583	1.734623	1.509934	-1.665102	0.950019	0.080128	0.355479
37	0.021879	0.130884	0.269830	0.175574	-1.005999	0.255774	-0.681091	-0.394976

Figure 2. Normalization results.

3.3. Model Tuning

The tuning model as part of the process to determine the most optimal K value is carried out using the elbow method, where the results of the elbow method are shown in Figure 3.

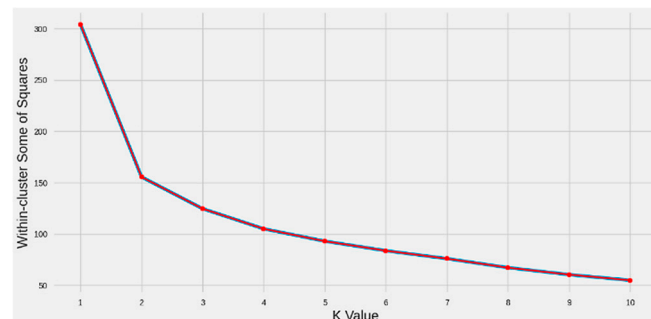


Figure 3. Elbow graphic.

The value of 2 on the K value line is the value that is the beginning of the smoothness of the graph. Therefore, the most optimal value for creating a cluster in these data is $K = 2$.

3.4. Model Building

The model is made by setting the cluster value (i.e., 2) as the basis for division. The dataset will then be divided by the system into two groups based on the similarity of the characteristics of each data. The syntax used in the model building can be seen in Figure 4. The results of these data sharing will be visualized at a later stage.

```
model=KMeans(init="random",n_clusters=2)
model.fit(std_atr)
print('inertia:',model.inertia_)
print('cluster_centroids:',model.cluster_centers_)
```

Figure 4. Model building.

3.5. Model Visualization

Model visualization is realized by changing the data dimensions that initially existed in eight dimensions to two dimensions. The process of changing this dimension is carried out using the Principle Component Analysis (PCA) method, as shown in Figure 5. The dimensions that have been changed will be mapped in a scatterplot to map various points in the Cartesian plane so that it can be easier to observe what points are included in cluster 1 and cluster 2. The cluster visualization in the Cartesian plane is presented in Figure 6.

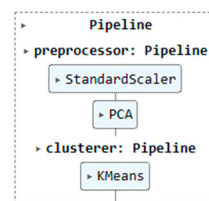


Figure 5. PCA usage.

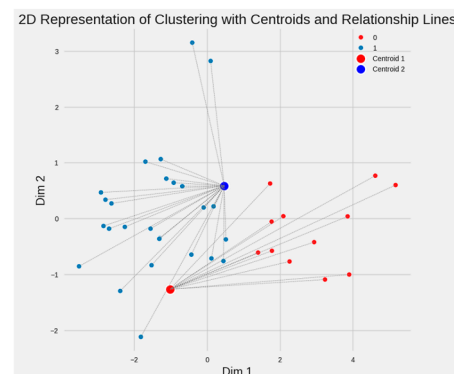


Figure 6. Cluster visualization.

Based on the cluster method, the results of the clustering of Batik SMEs were obtained. The results show that Batik SMEs can be differentiated into two clusters.

The cluster results are presented in Table 1. The Silhouette Coefficient column shows the quality or accuracy of Batik SMEs entering the cluster. The cluster value itself is in the range of -1 to 1 ; the closer the coefficient value is to the value of 1 , the more suitable or precise the placement of data in the cluster in question, and vice versa. The table above shows that the Silhouette Coefficient value range in cluster 0 is larger than that of cluster 1. This difference in range shows the diversity of data in the cluster. Cluster 0 with a larger number of members than cluster 1 is more diverse compared to cluster 1, which has a smaller number of members. Thus, cluster 1 can be said to be more homogeneous compared to cluster 0. This cluster division can be explained through analysis based on the table of answers from respondents.

Table 1. Cluster results.

Cluster	Silhouette Coefficient Range	Members (Index)
0	0.578–0.047	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 22, 24, 25, 28, 32, 33, 34, 35, 36, 37
1	0.521–0.217	16, 17, 18, 19, 20, 21, 23, 26, 27, 29, 30, 31

3.6. Cluster 1 (0)

Cluster 1 is a cluster with a total of 26 entities. Some of the characteristics that can be known based on the analysis of the contents of the cluster are as follows.

Cluster 1 (0) has the most values of 5 and 6 on all question characteristics. Values of 5 and 6 indicate that cluster 1 tends to agree on all questions.

The dominance of the five values in the answer shows a tendency to quite agree with the following statements:

1. (X1) Based on the efficient use of materials, most SMEs feel that the use of materials when carrying out production is quite efficient.
2. (X3) Based on the efficient use of energy, most SMEs feel that the use of energy for production is quite efficient.
3. (X5) Based on the waste from production, most SMEs feel that the waste produced in the production process is quite environmentally friendly.

The dominance of six in the answer shows a tendency to agree with the following statements:

1. (X4) Based on the efficient use of water, most SMEs feel that the use of water for production is efficient.
2. (X6) Based on the ideas given by external partners, SMEs agree that external partners provide ideas for waste treatment innovations in the production process.
3. (X7) Based on the design of external partner innovation, SMEs agree that external partners, together with the organization, design waste treatment innovations in the production process.
4. (X8) Based on the use of new technology by the organization, SMEs agree that the organization utilizes new technology from external partners for waste treatment innovation in the production process.

The dominance of 5–6 in the answer shows a tendency to agree with the following statement:

1. (X2) Based on the use of environmentally friendly materials, most SMEs feel that the use of materials for production is quite environmentally friendly.

So, it can be concluded that cluster 1 was formed as a result of the answers from respondents to all questions dominated by values ranging from 5 to 6, with the tendency of SMEs to agree with the existing statements.

3.7. Cluster 2 (1)

Cluster 2 is a cluster with a total of 12 entities. Some characteristics that can be known based on the analysis of the filling in the cluster are as follows.

Cluster 2 (1) scores of 3 and 4 are the most in all the characteristics of the question, with a total score of 7 not present at all. Some variables are dominated by values of 5 to 2.

The dominance of the value of 5 in the answer shows a tendency to agree with the following statements:

1. (X4) Based on the efficient use of water, most SMEs feel that the use of water for production is quite efficient.
2. (X7) Based on the innovation design of external partners, SMEs are neutral in thinking that external partners, together with the organization, design waste treatment innovations in the production process.

The dominance of the value of 3 in the answer shows a tendency for SMEs to disagree with the following statements:

1. (X3) Based on the efficient use of energy, most SMEs feel that the use of energy for production is not efficient enough.
2. (X5) Based on the waste from production, most SMEs feel that the waste produced in the production process is not environmentally friendly enough.

The dominance of the value of 2 in the answer shows the tendency of SMEs to disagree with the following statement:

1. (X2) Based on the use of environmentally friendly materials, most SMEs feel that the use of materials for production is not environmentally friendly.

The value of 2–4 indicate disagreement with the following statements:

2. (X6) Based on the ideas given by external partners, SMEs do not agree that external partners provide ideas for waste treatment innovations in the production process.
3. (X8) Based on the use of new technology by the organization, there is a lack of agreement among SMEs that the organization utilizes new technology from external partners for waste treatment innovation in the production process.

So, it can be concluded that cluster 2 was formed as a result of the respondents' answers to all questions dominated by values ranging from 2 to 5, with the tendency of SMEs to disagree with the existing statements

3.8. Discussion

The first cluster tends to have higher environmental sustainability achievement and open innovation involvement than the second cluster. The members of the first cluster can use open innovation to achieve environmental sustainability. In environmental sustainability, the key variables that are most explosive between cluster 1 and cluster 2 are the use of environmentally friendly materials and energy efficiency. Cluster 1 is more selective in choosing the materials used, such as waxes, dyes, and other chemicals, than in the use of energy; cluster 1 tends to use energy more efficiently, using it according to the needs of the predetermined process.

In open innovation, the key variable that most distinguishes cluster 1 from cluster 2 is the involvement of external partners to provide innovative waste treatment ideas. Members of cluster 1 tend to be active in establishing cooperation with external partners, for example, with universities, so that they receive a variety of innovations, including in waste management. On the other hand, the second cluster needs more attention from external stakeholders to encourage and support them in achieving environmental sustainability, primarily related to using environmentally friendly materials in production. SMEs in the second cluster still struggle to access external technologies. Local government and industrial associations can play a significant role in providing this access.

The size of the IKM does not determine where an IKM is located in a particular cluster. Not all medium-sized SMEs are in cluster 1. This shows that although medium-sized SMEs have more resources, awareness of environmental sustainability is not necessarily high either. The age of the IKM does not determine that the IKM is in a certain cluster. Not all SMEs that have been operating for more than 100 years are in cluster 1. This shows

that more experience does not make them more aware of environmental sustainability. Awareness of environmental sustainability depends on the owner's priorities.

4. Conclusions

In this study, two clusters have been formed. Cluster 1 consists of 26 SMEs with certain characteristics; they can use open innovation to achieve environmental sustainability. They can gain access to the idea from external partners and build collaboration. Cluster 2 consists of 12 SMEs with the following characteristics: low environmental sustainability and low utilization of open innovation. They need more attention from external stakeholders to encourage and support them in achieving environmental sustainability through open innovation.

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