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Factor Impacts and Target Setting of Energy Consumption in Thailand Sanitary Ceramics Industry

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This paper conducts the influence factor analysis of comprehensive energy consumption and Target Setting based on a Thailand sanitary ceramics sector by multiple regression analysis. Energy consumption of sanitary ceramics manufacture were collected from four factories, which consumed 75 % of energy consumption in sanitary ceramics sector. This sector has been proportion of energy consumption were thermal energy accounting 85 % and electrical 15 % of energy consumption. The tunnel kiln is the main machine that hold 76 % of thermal energy and the rest is used for drying system. The result of regression analysis could be explained that according to the polynomial equation representing the coefficient among four variables. Factor Impacts of Energy Consumption in Thailand Sanitary Ceramics Industry were Product (X_1), Raw Material (X_2) and Working Hour (X_4). Setting up of the target for reducing energy consumption of sanitary ceramics sector to propose the mix approaches of “Top-down” and “Bottom-up inconsistency with the national energy target.

1. Introduction

Energy is an important input for providing the basic services of human needs and is a key input to sustainable development and poverty reduction efforts. The role of energy is strongly linked to social, economic, and environmental development (Martchamadol and Kumar, 2012). Encouraging the use of renewable energies and the improvement of energy efficiency in industrial processes through the implementation of Energy Management Systems, which allows to reduce the energy consumption in 37 % of the current worldwide industrial energy consumption (Valencia et al., 2017). Industrial sector is considered as one of the major economic and energy intensive sector in Thailand at around 36% of total final energy consumption in 2015. The energy efficiency improvement in this sector is essential and challengeable to study. This study focuses on the energy baseline and target setting in sanitary ceramic sector which have around 19 % of energy consumption and around 35 % of GDP from total ceramic business in Thailand.

2. Background

Thailand’s energy management database in 2015, there are 10 sanitary ware factories, which is main the type of ceramic industry. Energy consumption amounted to 2,759 TJ, accounting for 12 % approximately of ceramics sector. The ceramic sanitary industry is one of energy intensive industries (Chuenwong et al., 2017). The primary energy use in ceramic manufacturing is for kiln firing and, in many processes, drying of intermediates or shaped ware is also energy intensive (European Commission, 2007). Greenhouse gas (GHG) emissions, especially CO_2, are mainly associated with the use of energy in the kiln and spray dryer (International Finance Corporation, 2005). The analysis of influencing factors is a problem worth exploring for the manufacturing enterprise. Because of manufacturing production, production products must consume the necessary energy (Tso et al., 2013). This paper attempts to analyse the factors which impact the energy consumption of sanitary ceramics industries by study in the four factories, which consumed 75 % of energy consumption in sanitary ceramics sector. Thermal energy (within the boundaries of gate-to-gate) are consumed in the drying and firing process and electrical are consumed in raw materials and mixing, casting, spraying and QC inspection & packing process flow that presented in Figure 1.

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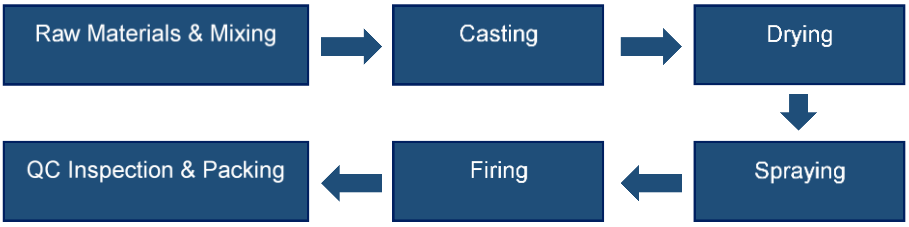


Figure 1: Sanitary ceramics processes

3. Study method

Multiple regression analysis is used to establish relationship between each indicator and comprehensive energy consumption were evaluated for four factories, and hot spots of energy consumption were identified. This model can be much more realistic than the uni-factorial regression model (Zsuzsanna and Marian, 2012). Actual consumption data record for 2016 from national designated factory database. This data was divided into data set to be used in a multiple regression analysis to generate energy equation.

3.1 Energy baseline

The Energy Utilization Index (EUI) or Specific Energy Consumption (SEC) is determined by the total energy consumption of designated factory (both of electricity and thermal energy) and product output is quantity of the product (Malakrong et al., 2017) referenced as Eq(1)

$$EUI = SEC = \frac{\sum Energy}{Product\ Output} \tag{1}$$

Regression analysis is the mathematical statistics method treating the statistical correlation of the variables, with the basic thought to find the mathematical expression form representing the relationship between independent variable and dependent variable. The regression analysis with two or more independent variables is called multiple regression (Yang et al., 2017). Multiple linear regression analysis seeks to establish a relationship between a dependent variable and two or more independent variables (the predictors) in the form (Braun et al., 2014) reference as Eq(2)

$$Y = b_0 + b_1(X_1) + b_2(X_2) + b_3(X_3) + \ldots + b_n(X_n) + \in \tag{2}$$

b_0, $b_1 \ldots b_n$ are the regression coefficients, and $\in$ is an error.
The predictors should have little or no correlation with each other (i.e. the correlation coefficient should be less than 0.7) to avoid problems caused by multicollinearity. The last term in the equation, e, is referred to as the residual (or fitted error) and is used for testing the overall significance (F-test) of the equation and the significance of each regression coefficient (t-test).

3.2 Target Setting

Establishment of energy consumption norms and standards for designated consumers in the sanitary ceramics sector, the designated consumers have been grouped based on similar major product for benchmarking of their Specific Energy Consumption (SEC) performance (Bureau of Energy Efficiency, 2015).
Energy saving will analyses sector-specific energy consumption pattern and bandwidth of SEC the factories to calculate the achievable energy saving from implementing the proposed eligible measures/activities compare with base year. The energy reduction potential by using the SEC from previous section compared to the SEC of the best practice.

4. Results

Usage Pattern of energy (Electrical and Natural Gas) are used in sanitary ceramics production. This sector has been proportion of energy consumption were thermal energy accounting 85 % and electrical 15 % of energy consumption. The tunnel kiln is the main machine that hold 76 % of thermal energy and the rest is used for drying system (drying the excess moisture in workpieces and mold drying). The energy usage pattern in sanitary ceramic industry presented in Figure 2.

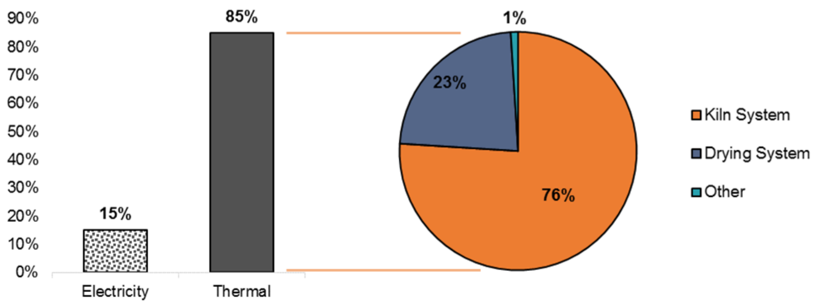


Figure 2: Energy Usage Pattern in sanitary ceramic industry

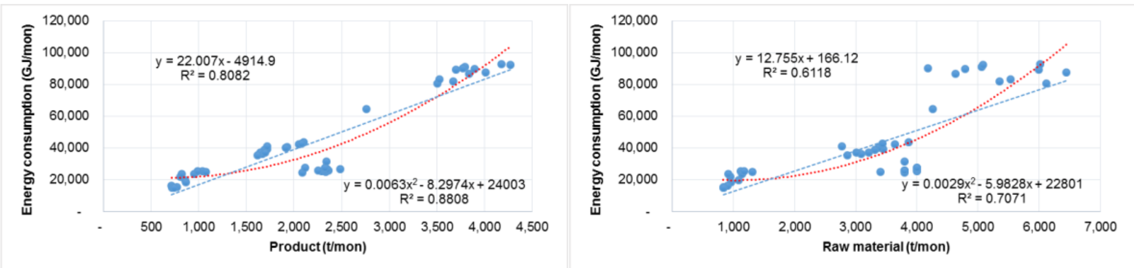
Multiple regression attempts to model the relationship between two or more explanatory variables, value of the independent variable X is associated with a value of the dependent variable Y. The energy data would be applied by multiple regression method to analyse factors, which impact the energy consumption of sector. The factors that impact of energy presented in Table 1 and Table 2.

Table 1: Dependent variables (Y)

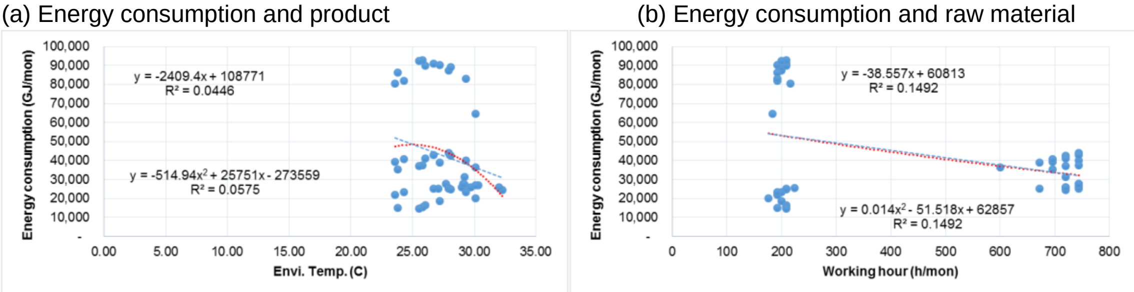
Variable	Description	Unit
Y_{Elec}	Electrical Energy Consumption	GJ
$Y_{Thermal}$	Thermal Energy Consumption	GJ
Y_{Total}	Total Energy Consumption	GJ

Table 2: Explanatory/independent variables (X)

Variable	Description	Unit
X_1	Product	t/mon
X_2	Raw material	t/mon
X_3	Environment temperature	ºC
X_4	Working hour	h/mon



(a) Energy consumption and product (b) Energy consumption and raw material



(c) Energy consumption and envi. temp. (d) Energy consumption and working hour

Figure 3: Relationships between variable in sanitary ceramics

Figure 3 shows relationships between variable, displays the plots of input data, showing a non-linear relationship is acceptable between the independent variables and output. Therefore, a non-linear equation can be formulated reference as Eq(3).

$$Y = C_1(X_1) + C_2(X_2) + C_3(X_4) + C_4(X_1)(X_2)(X_4) + C_5(X_1^2) + C_6(X_2^2) + C_7(X_4^2) + C_8 \quad (3)$$

C_1, C_2… C_8 are constant
The final regression polynomial equation of sanitary ceramics sector is calculated:

$$Y_{Elec} = 2.275(X_1) + 2.196(X_2) -14.026(X_4) -5.649\times10^{-7}(X_1)(X_2)(X_4) + 0.013(X_4^2) + 532.389 \quad (4)$$

Electrical energy consumption reference as Eq(4) with parameters of quality analysis as $R^2 = 0.992$

$$Y_{Thermal} = 6.754(X_1) + 9.621(X_2) -57.025(X_4) -1.152\times10^{-5}(X_1)(X_2)(X_4) + 0.003(X_1^2) + 9.05\times10^{-7} (X_2^2) + 0.119(X_4^2) + 9{,}037.767 \quad (5)$$

Thermal energy consumption reference as Eq(5) with parameters of quality analysis as $R^2 = 0.969$

$$Y_{Total} = 9.029(X_1) + 11.818(X_2) -71.051(X_4) -1.208\times10^{-5}(X_1)(X_2)(X_4) + 0.003(X_1^2) + 0.132(X_4^2) + 9{,}570.159 \quad (6)$$

Total energy consumption reference as Eq(6) with parameters of quality analysis as $R^2 = 0.977$
The result could be explained that according to the polynomial equation representing the coefficient among 4 variables, dependent variables were significant consisted in the energy consumption (Electrical energy consumption, Thermal energy consumption and Total energy consumption), while the independent variables were the following: Product (X_1), Raw Material (X_2) and Working Hour (X_4). Using Pearson correlation analysis to determine the causal relationship between each indicator and comprehensive energy consumption, envi. temp (X_3) and Working Hour (X_4) there were multicollinearity between two variables, Working Hour (X_4) entered in the equation. Parameter estimates test of multiple regression analysis (Total Energy Consumption) presented in Table 3. Figure 4 shows the prediction of relationship between predicted energy consumption with actual energy consumption.

Table 3: Parameter estimates test of multiple regression analysis (Total Energy)

Parameter	Estimate	Std. Error	95 % Confidence Interval	
			Lower Bound	Upper Bound
C_1	9.029	14.604	-20.487	38.545
C_2	11.818	8.746	-5.859	29.494
C_3	-71.051	55.679	-183.583	41.482
C_4	-1.208×10^{-5}	.000	-1.486×10^{-5}	-9.304×10^{-6}
C_5	.003	.002	-.001	.007
C_6	.000	.001	-.002	.002
C_7	.132	.062	.007	.257
C_8	9,570.159	10,431.431	-11,512.550	30,652.868

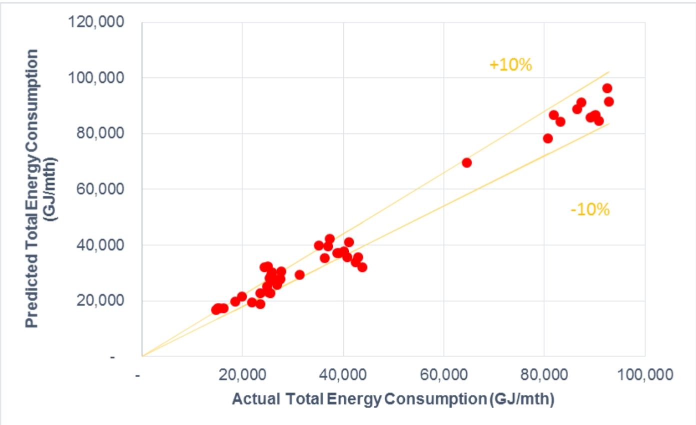


Figure 4: Relationships between actual energy consumption and predicted consumption.

This study proposed the mix approaches of “Top-down” and “Bottom-up” were adopt, with detailed bottom-up studies (SEC level from baseline study) set within a top-down framework (national goal Energy Efficiency Plan (EEP2015) of the Ministry of Energy of the Kingdom of Thailand) for sanitary ceramics sector as illustrated in figure 5. The result shown in Figure 6 indicated the potential SEC of the best practice in sanitary ceramics sector accounting for 17.89 ktoe.

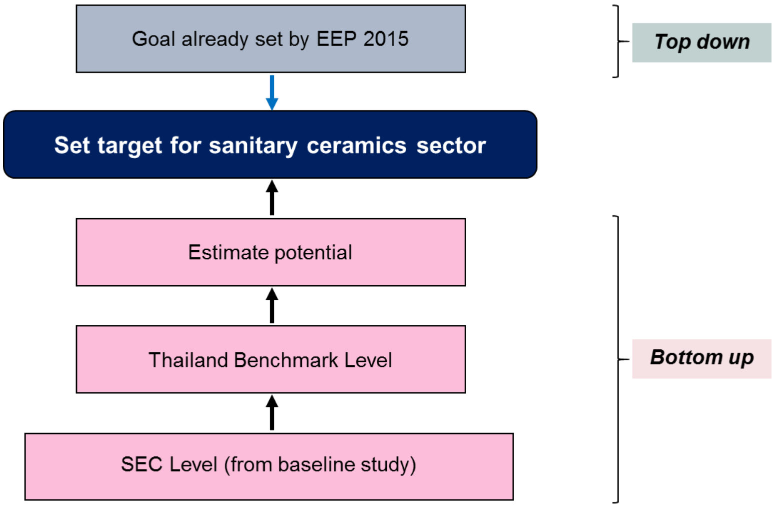


Figure 5: Schematic representation of an integrated Top-down and Bottom-up Approach.

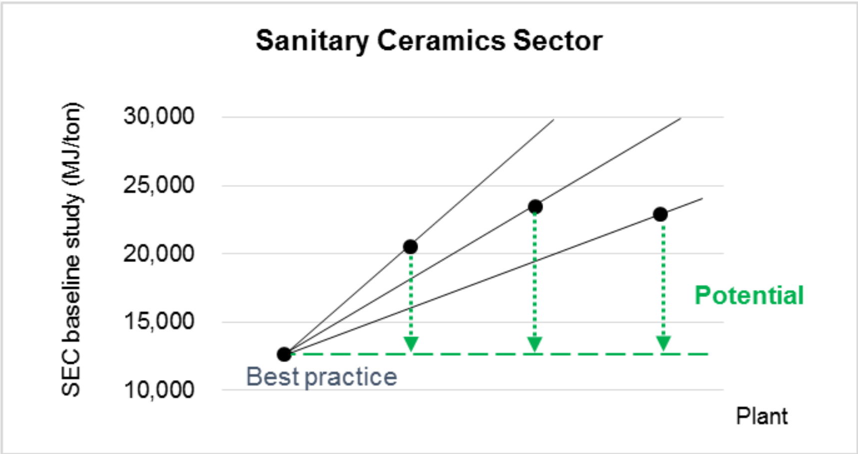


Figure 6: Show results of potential assessment from SEC of the best practice

5. Conclusions

This paper conducts the influence factor analysis of comprehensive energy consumption and Target Setting based on a Thailand sanitary ceramics sector by multiple regression analysis. The energy usage pattern consumption by end-use systems has been analysed figuring out the kiln system accounting for 76 % of total thermal energy. From the data presented above can draw the following: three of the performance indicators, namely the Product (X_1), Raw Material (X_2) and Working Hour (X_4) are significant predictors for the dependent variable, namely the energy consumption (Electrical, Thermal, Total), in the analysed 2016. Thailand long-term EEP2015 (Top-down Approach) which is energy efficiency plan 2015 - 2036. The main target of this plan is to reduce Energy Intensity (EI) of Thailand by 30 % in 2036 from 2010 as based year or equivalent to a reduction of final energy consumption of approximately 56,142 ktoe, the Ministry of Energy has not only recognized the previous energy conservation results which helped reduce the EI from 15.28 to 14.93 ktoe/1,000 MBaht in 2013, accounting for accumulative energy savings achieved of 4,442 ktoe, but also considered possibilities and potential in practical terms in industrial sector with one in ten measure for additional evidence based results of 14,515 ktoe as under energy conservation targets based on the Energy Efficiency Plan during the period of

2015 - 2036 (Annual target 2016 of energy saving in designated factories accounting for 546 ktoe and Sanitary Ceramics Sector accounting for 0.6 ktoe). The plant baseline resulted from the regression method (Bottom-up Approach) were compared the SEC of best practice of 2016. According to comparability concept, the potential for reducing has been evaluated within a Thailand context, opportunities to saving over 50 % (accounting for 17.89 ktoe) of energy consumption in the sanitary ceramics sector. Setting up of the target for reducing energy consumption of this sector to propose “Top-down” and “Bottom-up” approaches in short-term for 3 y (2018-2020). The potential of best practice in Thailand is 57.46 ktoe.

References

Braun M.R., Altan H., Beck S.B.M., 2014, Using regressing analysis to predict the future energy consumption of a supermarket in the UK, Applied Energy, 130, 305-313.

Bureau of Energy Efficiency, Government of India, 2015, Normalisation methodology for cement sector <beeindia.gov.in/sites/default/files/Cement-1-44.pdf> accessed 13.03.2018.

Chuenwong K., Chiarakorn S., Sajjakulnukit B., 2017, Specific energy consumption and carbon intensity of ceramic tablewares: Small enterprises (SEs) in Thailand, Journal of Cleaner Production, 147, 395-405.

European Commission, 2007, Reference document on best available techniques in the ceramic manufacturing industry <eippcb.jrc.ec.europa.eu/reference/BREF/cer_bref_0807.pdf> accessed 13.03.2018.

International Finance Corporation, 2005, Environmental health and safety guidelines for ceramic tile and sanitary ware manufacturing <ifc.org/wps/wcm/connect/7cbada00488557a9bd4cff6a6515bb18/Final+-+Ceramic+Tile+and+Sanitary+Ware.pdf?MOD=AJPERES> accessed 13.03.2018.

Malakrong P., Wongsapai W., Damrongsak D., 2017, Analysis of energy utilization index in Thailand sanitary ceramics sector, Energy Procedia, 141, 170-174.

Martchamadol J., Kumar S., 2012, Thailand’s energy security indicators, Renewable and Sustainable Energy Reviews, 12, 6103-6122.

Tso K. G., Liu F., Liu K., 2013, The influence factor analysis of comprehensive energy consumption in manufacturing enterprises, Procedia Computer Science, 17, 752-758

Valencia E. G., Cardenas Y., Ramos S. E., Morales A., Campos C. J., 2017, Energy saving in industrial process based on the equivalent production method to calculate energy performance indicators, Chemical Engineering Transactions, 57, 709-714.

Yang N., Li Z., Feng Y., 2017, Empirical study for influencing factors on environmental accounting information disclosure in chemical industry, Chemical Engineering Transactions, 62, 1591-1596.

Zsuzsanna T., Marian L., 2012, Multiple regression analysis of performance indicators in the ceramic industry, Procedia Economics and Finance, 3, 509-514