ESTIMATING ELECTRICAL ENERGY GENERATION FROM HUMAN MUSCLE EFFORTS

R. Halfeld – R. Castro – M. Cohen – E. Castro

Abstract. This paper aimed to develop a model to estimate the generation of electrical energy through human muscular effort, using a generator bicycle, connected to the electrical grid. The motivation resulted from the author's experience in distributed electric energy generation, which identified a difficulty in installing photovoltaic solar generation systems on the top of buildings. As a research methodology, this study used Multiple Linear Regression using time, weight, height, and body mass index (BMI) as independent variables. The model showed promising results, presenting a high adjusted R-squared, respecting the assumptions associated with a linear regression model. The simulations based on the model showed a considerable energy generation potential for Brazil. In conclusion, although the estimated regression model presented a high predictive capability, further studies are recommended before any financial investment.

Keywords: Renewable energy, muscle effort, health indicators, harnessing human energy, multiple linear regression.

1. Introduction

The modern world is dependent on electrical energy and its demand continues to rise. Traditionally, 80% of the demand is supplied with non-renewable sources that harm the environment such as greenhouse gases and other chemicals that cause acid rain. The environmental agenda promoted by the 2016 Paris Agreement prevents this percentage from maintaining or increasing, stimulating the search for other sources of energy generation. So, energy efficiency promotion becomes even more critical [1].

From all green/renewable energy sources available, *Santa Rita do Sapucaí* Penal Institution, in the state of Minas Gerais (Brazil), chose a very different one: energy from its inmates. In this experimental program, they can reduce their sentence time by generating electricity through a spinning bicycle [2].

Observing that program, the main objective of this paper is to create a model for estimating the electric energy generation from muscle effort.

Picture 1: Inmates of Santa Rita do Sapucaí [2]

2. Methodology and Data

For this study, a generator bicycle was developed to measure electrical energy generation through cycling. For data collection, 40 people cycled and the electrical energy generation (Wh) was measured. The experiment was conducted in Colombia.

This study used Multiple Linear Regression as the statistical technique. It assumes that the dependent variable is a linear function of the independent ones. The multiple linear regression equation can be expressed as follows [3]:

$$Y = \beta_0 + \beta_1 X_1 + ... + \beta_p X_p + \varepsilon \qquad (1)$$

The first independent variable of the regression model of this study was time. This is due the fact that electric energy is measured in hours, e.g., kWh. The other independent variables were physiological, according to the cyclist's physical features. The dependent variable was electrical energy.

In the absence of other studies that relate biological values to electric energy, it was decided to interview Professor Barragat, a Medical Doctor (MD) that teaches at *Divinópolis* campus of the *São João Del Rey* Federal University, Brazil. Barragat recommended both weight and height and the Body Mass Index (BMI) as possible explanatory variables.

Table 1 shows the Pearson correlation between electrical energy and the variables.

Table 1: Pearson Correlation Coefficient

Variables	Coefficient
Eletrical Energy and Time	0.9014
Eletrical Energy and Weight	0.4553
Eletrical Energy and Height	0.8047
Eletrical Energy and BMI	0.0212

Table 2 shows the sample descriptive statistics. The sample was collected in Colombia, where the bike/generator was built. Data was collected during the last week of November 2021 and has 40 observations.

Table 2: Sample Descriptive Statistics

Descriptive Statistics	*Eletrical Energy (Wh)*	*Time (s)*	*Weight (kg)*	*Height (m)*	*BMI*
Minimum	10.160	63.000	44.400	1.550	15.184
Maximum	226.780	552.000	92.700	1.850	33.695
Average	74.048	245.525	69.413	1.695	24.134
Median	70.065	260.000	69.850	1.698	24.784
Standart Deviation	47.161	104.743	12.881	0.080	4.029

The generator was based on the study of Swati M. & Anagha [4], as Fig.1 shows.

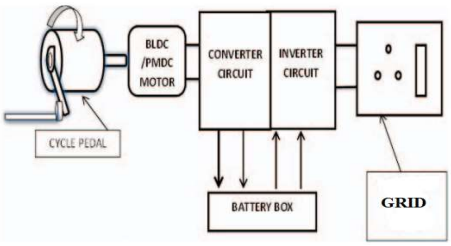

Figure 1: Generator Diagram [4]

3. Results

Table 3 presents the estimated coefficients after the IBM SPSS regression. As assumed, weight and BMI were excluded from the model.

Table 3: Estimated Coefficients

Model	Coefficient	Std. Error	t	*p*-value
Constant	-341.049	76.452	-4.461	<0.001
Time (s)	0.298	0.037	8.053	<0.001
Height (cm)	2.016	48.674	4.144	<0.001

Therefore, the estimating equation can be expressed as follows:

$$\hat{Y} = -341.049 + 0.298X_1 + 2.016X_2 \qquad (2)$$

Applying the linear regression equation and using the anualized miminum exercise time, according to World Health Organization [5] , a human can generate aproximatly 140 kWh/y.

Table 4: Single Predictions

kWh*	seconds	centimeters
139.77	468.000	150
139.87	468.000	200

*kWh = Predicted Eletrical Energy

4. Conclusion

Regarding the general objective of developing a prediction model of electrical energy generation from human effort, the work succeeded to arrive at an equation that allows reasonable "What if Analysis" in predicting electrical energy generation from human effort. The model can be improved in many ways, such as considering a larger sample size, as well as other possible explanatory variables, for example, age and body composition index. However, it is a promising approach as the good results presented in this paper were generated via a straightforward use of Multiple Linear Regression. Other approaches that measure the relationship of variables, not necessarily linear ones, could improve the model. It is extremely important to carry out further studies as mentioned above, before making an investment in this source of electrical energy.

Acknowledgement

This paper would not be possible without the financial support of *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES) and infrastructure support of *Pós-MQI* (Metrology and Industrial Quality) Program from PUC-Rio university.

References

[1] L. Dias, G. Lima, D. Rodrigues, "Sistema de Geração de Energia Elétrica a partir de uma Bicicleta Ergométrica"; [2]O GLOBO. Presos Pedalam e Ajudam a Iluminar Praça em Santa Rita do Sapucaí, MG; [3] D. Montgomery, et al. Introduction to Linear Regression Analysis. John Wiley & Sons, 2012; [4] S. Mudaliar, A. Soman, "Electrical power generation harnessing human energy and its analysis". IEEE International Conference on Energy Systems and Applications (2015). pp. 333-337.; [5] World Health Organization, accessed November 30th 2021, <https://apps.who.int/iris/bitstream/handle/10665/336656/9789240015128-eng.pdf?sequence=1&isAllowed=y>.