ESTIMATING ELECTRICAL ENERGY GENERATION FROM HUMAN MUSCLE EFFORTS

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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 electrical 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.

Key words. 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.

2. Methodology and Data

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

This study used Multiple Linear Regression as research method. Linear regression is one of the most used statistical methods in practice. Its applications can be used in various scientific fields such as: medicine, biology, agriculture, economics, engineering, sociology, geology, among others.

Multiple linear regression is a linear regression model with one dependent variable and two or more independent variables. It assumes that the dependent variable is a linear function of the independent ones. The multiple linear regression formula can be expressed as follows [3]:

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

Where Y is the dependent variable, X_1, … X_p are the p independent variables, β_0, β_1, …, β_p are the parameters, and ε is a random error term.

In this study, both Forward Selection and Backward Elimination methods were used for variables selection and the software used was the IBM SPSS Statistics.

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.

According to Barragat, weight is a basic indicator of medicine, being in practically all medical decision making, from current health to medication prescription. Sick people tend to lose mass during illness, and rapid (unplanned) loss of mass is also often indicative of a serious illness.

Height is an indicator of body development used as a sign of healthy intake and good body development. It is not uncommon to observe athletes with a height considerably above the population average height.

The BMI was created in the 19th century with the aim of identifying a person's ideal weight. It is a variable derived from two other quantities (weight and height), and is calculated according to the formula:

$$BMI = Weight / Height^2 \qquad (2)$$

The interviewee also mentioned that BMI may not be a good explanatory variable, because it does not differentiate the weight of fat mass (fat) from the weight of lean mass (muscle), and, because of that, is being replaced by other indexes, like body composition.

Table 1 shows the sample descriptive statistics. The sample was collected in Colombia, where the bike/generator was built. The data was collected during the last week of November 2021 and has 40 observations.

Table 1. – 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

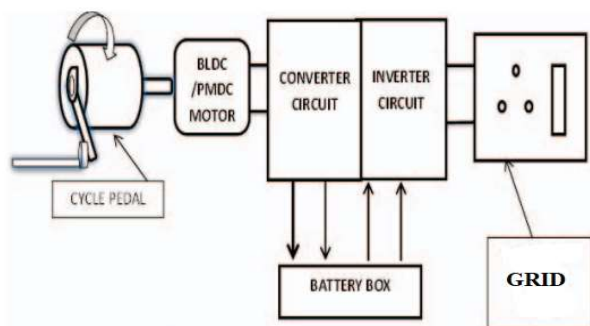The generator was based on the study of Swati M. & Anagha (2015), as Fig.1 shows.

Figure 1. Generator diagram [4]

Like a conventional bicycle, legs and feet muscle force spins the bikes pedal. This pedal is connected to an alternate current (AC) generator. The converter transforms to direct current (DC) and is also a charger controller. The battery

receives that energy and stores it. The inverter, collects the DC electrical energy from the battery, transforms it in AC again, and then injects it in the domestic grid.

3. Results

The first result was the Pearson Correlation Coefficient, between the generated electricity and the independent variables, showed in Table 2.

Table 2. – 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

Both methods (Forward Selection and Backward Elimination) selected the independent variables "time" and "height" for the regression model, to explain the "generated electrical energy".

The main results of the linear regression model are shown on Table 3 and Table 4.

Table 3. – Model summary

Variables	Coefficient
R-Squared	0.872
Adjusted R-Squared	0.865
Std. Error of the Estimate	17.323

The adjusted R-squared means that the model can explain 86.5% of the variation in the "electrical energy generation". Thus, this model has a good predictive capacity.

The result of the F-test indicates that the null hypothesis, that all regression coefficients are equal to zero, is rejected (*p*-value < 0.001)

The VIF statistic (1.958) showed that the model does not have collinearity problem.

Table 4. – 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

The interpretation of the slope coefficients is as follows:

Estimated Beta 1 = 0.298 indicates that for each second in the exercise, the amount of energy (kW) generated increases, on average, by 0.298 kW.

Estimated Beta 2 = 2.016 indicates that for every centimeter in height, the amount of energy (kW) generated increases, on average, by 2.016 kW.

Therefore, the regression model is expressed as follows:

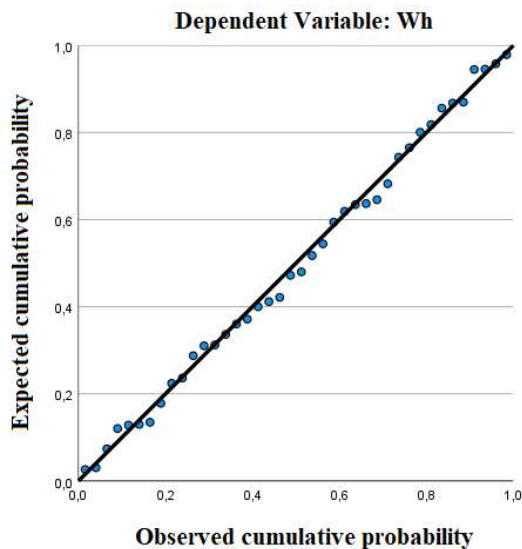$$\hat{Y} = -341.049 + 0.298X_1 + 2.016X_2 \qquad (3)$$

Dependent Variable: Wh

Figure 2. Normal P-P Plot graph

By the Normal P-P Plot (Figure 2), we can conclude that the assumption of normality was met.
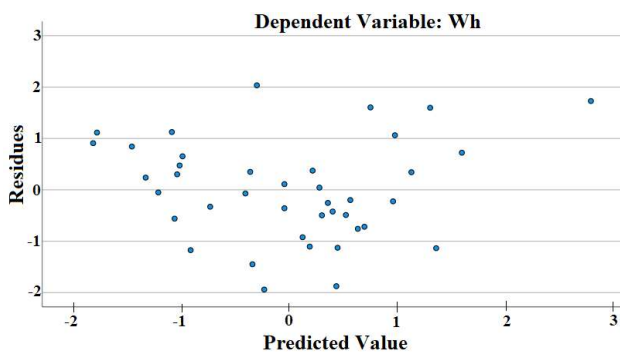
Dependent Variable: Wh

Figure 3. Scatter Plot graph

Based on the scatter plot (Figure 3), it is observed that the assumptions of linearity, homoscedasticity, and serial independence were met, as there is no defined pattern in the residuals.

Table 5 shows a forecasting using the estimated model, for the case of a single person, varying the height from 150 cm to 200 centimeters and a fixed time of 468 thousand seconds (130 hours), which is the annualized minimum recommended exercise time of 150 minutes (2.5 hours) per week [5]. The electrical energy generation differs by only 0.01%.

Table 5. – Single Person Prediction

kWh*	seconds	centimeters
139.77	468.000	150
139.87	468.000	200

*kWh = Predicted Eletrical Energy

Table 6. shows an estimation for the Brazilian inmate population, which is around 750,000 [6], respecting the fact that the program is not compulsory and that not all the prisoners are physically able to exercise.

Table 6. – Brazilian Inmate Population Prediction

Inmates	Predicted Energy generation (kWh)
750,000	104,849,864
375,000	52,424,932
250,000	34,949,955
187,500	26,212,466
150,000	20,969,973
75,000	10,484,986

4. Conclusions

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

References

[1] L. Dias, G. Lima, D. Rodrigues, "Sistema de Geração de Energia Elétrica a partir de uma Bicicleta Ergométrica", accessed January 12th 2022, < https://www.peteletricaufu.com.br/static/ceel/doc/artigos/artigos2016/ceel2016_artigo056_r01.pdf>.

[2] O Globo, accessed May 12th 2019, <http://g1.globo.com/mg/sul-de-minas/noticia/2012/06/presos-pedalam-e-ajudam-iluminar-praca-em-santa-rita-do-sapucai-mg.html>.

[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>.

[6] Prison Studies Organization, accessed January 12th 2022, <https://www.prisonstudies.org/country/brazil>.