A holistic framework for Empowering SME's capacity to increase their energy efficiency

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List of Acronyms

Acronym	Meaning
D	Deliverable
KPI	Key Performance Indicator
LU	Learning Unit
M.U.	Monetary Units
M&V	Measurement & Verification
M&T	Monitoring & Targeting

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Executive summary

This deliverable presents the second part of the SMEmPower online tool, which is under development in the framework of the project. The online tool will allow SMEs to undergo energy audits and increase their energy efficiency through effective implementations, which will be also measured and verified. The tool is divided into three parts which are: the data uploader, the M&T and the M&V tools, respectively. The data uploader tool, presented in D4.3 *Tools to upload energy readings*, allows the user to upload measurements either as files or manually via the user interface and these measurements are in turn used by the M&T and M&V tools. The M&T tool provides the energy managers with the trend regarding the so far energy consumption and with an estimation regarding potential energy savings that could be yielded under the implementation of energy efficiency measures. Additionally, it allows them to understand the correlation between energy consumption and production and have a clear idea regarding the energy usage in their installations.

Introduction

SMEmPower will develop and implement a common E&T program for energy professionals in eight (8) countries. In this program, the energy professionals will access and use the online energy management M&T and M&V tools that will be developed in the project. This is to be partially achieved through uploading energy utility measurements, production data, and other related data, to a dedicated tool for this reason. These data will be used by the system to provide results. The complete online tool can be separated in three parts, i.e. the data uploader, the M&T tool and the M&V tool. The data uploader has been presented in detail in D4.3 *Tools to upload energy readings*, and its main role is to allow the energy professionals to upload their energy readings to the SMEmPower efficiency tool. The data that are uploaded and stored to the database can be accessed and used by the M&T and M&V tools. The M&T tool provides the energy managers with guidance regarding the amount of energy that is consumed or expected to be consumed for a certain period of time. Additionally, it allows the energy manager to visualize the energy consumption trends and detect periods of time when the consumption differs from what could be named as normal or expected value. In this deliverable, the operation of M&T tool is presented.

1. General information

In order to access the tools or any protected material, the energy professionals must register on the website[1] as it has been previously presented in D4.2 *Web platform and portal release*. By logging in, the user will be able to access all restricted tools that can be found under the Results -> Tools menu at the header of the website. All the online tools that are also under development in the project are based on the offline excel tools that have been prepared earlier by the UTC and SERVELECT partners. Data entered to the tools are saved to the personal profile of each user and can be accessed and processed later.

2. Offline M&T excel tool

The offline excel tool includes all the three tools that will be developed online in the project. This variant is developed to run on usual operating systems (e.g. Windows) and consists of several sheets with different functionalities. For this deliverable, only the sheets that contain the part related to the M&T tool are used and presented in the following sections.

The M&T general objective is to manifest energy efficiency targets by exploiting energy management information. The M&T tool is built upon two concepts, namely “monitoring” and “targeting”. The monitoring concept refers to the collection of data that describe the energy use. The scope is to formulate the pattern of consumption and based on this pattern, energy management measure can be designed, implemented, and evaluated. The targeting concept

[1] https://www.smempower.com

defines the desirable energy consumption, i.e. an objective of reduced consumption in the future. The approach of the M&T in energy management studies is that loads of the SME, such as lighting, compressed air, electric drives, and others are controllable and can be managed. The same applies for various production processes such as building occupancy, raw materials, and others. Monitoring can be applied in aggregated level, e.g. total electrical consumption or individually per facility. Monitoring requires a diverse set of data, such us electrical consumption, thermal or fuel consumption, energy billings and variables that influence the consumption.

After the collection of the data, the next part is the visualization. The baseline consumption pattern is formed. Through the visualization, the user can examine the correlation of consumption and the factor(s) that influence it. The most common factor is the production of the SME. Also, other variables can be regarded, such as weather-related data, e.g. outdoor temperature. This examination is accomplished through regression analysis. Critical conclusions can be extracted regarding the level of influence of other variables on the consumption. The aim of the regression analysis is to quantify what drives energy consumption. In the targeting part, the user enters the desired reduction of the baseline consumption pattern. The user is asked to enter realistic consumption reduction targets and the expected time for the target to be manifested. It should be noted that the target setting could be dynamic; the user can modify future targets after the evaluation of historical performance of pre-existing energy efficient targets or other factors that influence the time evolution of the consumption. Thus, the targets can be revised. The target can be set either by using the best historical consumption data in terms of reduction, or by entering completely new values of demand that have not been observed in the past.

The next phase is the implementation of energy efficiency measures. The measures may include interventions on the equipment, such as replacement of existing lighting with energy efficient lamps, automation of some activities and processes, campaigns targeting to the personal to increase awareness and motivation on the benefits of energy efficiency and other organizational practices. After the implementation, the M&T is connected to the M&V tool. Here, the scope of measurement concept is to check the deviations of the new, i.e. updated consumption to the baseline consumption that was set in the M&T tool. This is a continuous process until the deadline of the consumption reduction target is met. In the M&V process, any deviations of the target reduction are corrected to accomplish as close as possible the target. The verification concept is the final evaluation of the implemented energy efficiency measure. This is held after the deadline.

2.1. Conversion lists

Prior to using the M&T Tool, the user must be aware of the conversion factors that are used throughout the tool. Thus, in the first sheet of the excel tool, which is called “conversion list”, the conversion tables that are needed are available as depicted below. The conversion coefficients in all respective tables are automatically applied in the tool based on user preferences regarding both the unit type of input data, and results. For example, in Table 1 the coefficients that are included and which would be applied to compute the CO2 emissions in [kg] for various unit types of consumption in the installation, are presented.

Table 1: Equivalent CO2 emissions

Equivalent CO2 Emissions			
Consumption Type		**Quantity per Unit Type**	
ID	Name	[kg CO2]	Unit
1	Electrical Energy	295,8	[MWh]
2	Thermal Energy	0,227	[MWh]
3	Natural Gas	1,9	[m^3]
4	Diesel	2,64	[liter]
5	Petrol	2,392	[liter]

Table 2: Conversion coefficients to [MWh] for Electrical Energy

Convertion Coeffs. to [MWh] for Electrical Energy		
ID	Unit	Coeff.
1	[toe]	11,63
2	[MWh]	1
3	[kWh]	0,001
4	[GWh]	1000

Table 3: Conversion coefficients to [MWh] for Thermal Energy

Convertion Coeffs. to [MWh] for Thermal Energy		
ID	Unit	Coeff.
1	[toe]	11,63
2	[MWh]	1
3	[Gcal]	1,163
4	[MBtu]	0,2933
5	[GWh]	1000
6	[kWh]	0,001

Table 4: Conversion coefficients to [MWh] for Natural Gas

Convertion Coeffs. to [MWh] for Natural Gas		
ID	Unit	Coeff.
1	[toe]	11,63
2	[MWh]	1
3	[m^3]	94,79
4	[GWh]	1000

Table 5: Conversion coefficients to [MWh] for Diesel

Convertion Coeffs. to [MWh] for Disel		
ID	Unit	Coeff.
1	[toe]	11,63
2	[MWh]	1
3	[ton]	0,084717
4	[liter]	84,7

Table 6: Conversion coefficients to [MWh] for Petrol

Convertion Coeffs. to [MWh] for Petrol		
ID	Unit	Coeff.
1	[toe]	11,63
2	[MWh]	1
3	[ton]	0,085984
4	[MJ]	0,0002777
5	[litre]	85,98

2.2. Electricity and fossil energy sheets

In the following two sheets, which are “electricity” and “fossil energy”, the user must enter the energy readings, as presented and explained in D4.3 *Tools to upload energy readings*, and the following table is automatically filled for each kind of energy:

Update Data	Total Active Electrical Energy Consumption							
Month	2019		2018		2017		2016	
	Amount [MWh]	Cost [M.U.]	Amount [MWh]	Cost [M.U.]	Amount [MWh]	Cost [M.U.]	Amount [MWh]	Cost [M.U.]
January	4.010	125.037	3.869	89.626	4.411	98.542	4.188	103.347
February	3.741	115.608	4.373	101.242	4.198	92.488	4.232	103.390
March	5.355	166.251	5.190	122.508	4.891	109.094	5.337	130.586
April	4.525	140.369	4.915	120.858	4.842	107.443	4.654	113.677
May	4.630	142.572	5.063	124.892	4.433	98.573	4.434	102.094
June	4.662	143.506	5.668	139.549	5.430	116.992	4.579	106.131
July	5.195	155.916	5.582	138.727	5.728	127.002	5.574	129.321
August	5.102	153.736	5.854	147.183	5.683	127.127	4.894	113.442
September	NaN	NaN	4.200	109.407	3.765	83.898	3.484	83.184
October	NaN	NaN	3.662	95.511	3.745	81.589	3.487	81.811
November	NaN	NaN	3.938	102.271	4.363	97.394	3.783	83.444
December	NaN	NaN	4.049	105.765	4.022	90.480	3.833	83.202
Total	37.220	1.142.994	56.363	1.397.540	55.510	1.230.623	52.480	1.233.630
Average	4.653	142.874	4.697	116.462	4.626	102.552	4.373	102.803

Figure 1: Electrical energy consumption table

The table in Fig.1 is filled with the monthly energy consumption of the installation, along with the respective energy cost in monetary unit selected by the user. Obviously, the energy consumption data could be entered by the user in various units, while the tool will convert them in [MWh] based on the right coefficient, as presented in section 2.1. At the bottom of the table, both the total, i.e. aggregated, and average values per annum are also calculated and provided to the user.

After the user has successfully entered the data, three graphs are plotted automatically for each of the energy types, i.e. electricity and fossil. The first graph depicts the yearly energy consumption, the second graph depicts the equivalent CO2 emissions and the third one depicts the yearly costs of electricity, as presented in the following three figures.

In Fig.2 the bar graphs embed energy consumption estimation that is illustrated with different colour than the one for the actual energy consumption. The meaning here is that based on past data and via a regression model that is applied (this will be explained in detail later on this document) the tool could provide estimation about the missing consumption values for the left months of the running year or even for the next years. This functionality is also valid for the tool outputs that are presented in Figs. 3 and 4 and is crucial since it could be highly appreciated by the users given that the estimation constitutes a projection in the future based on the trend that is monitored so far.

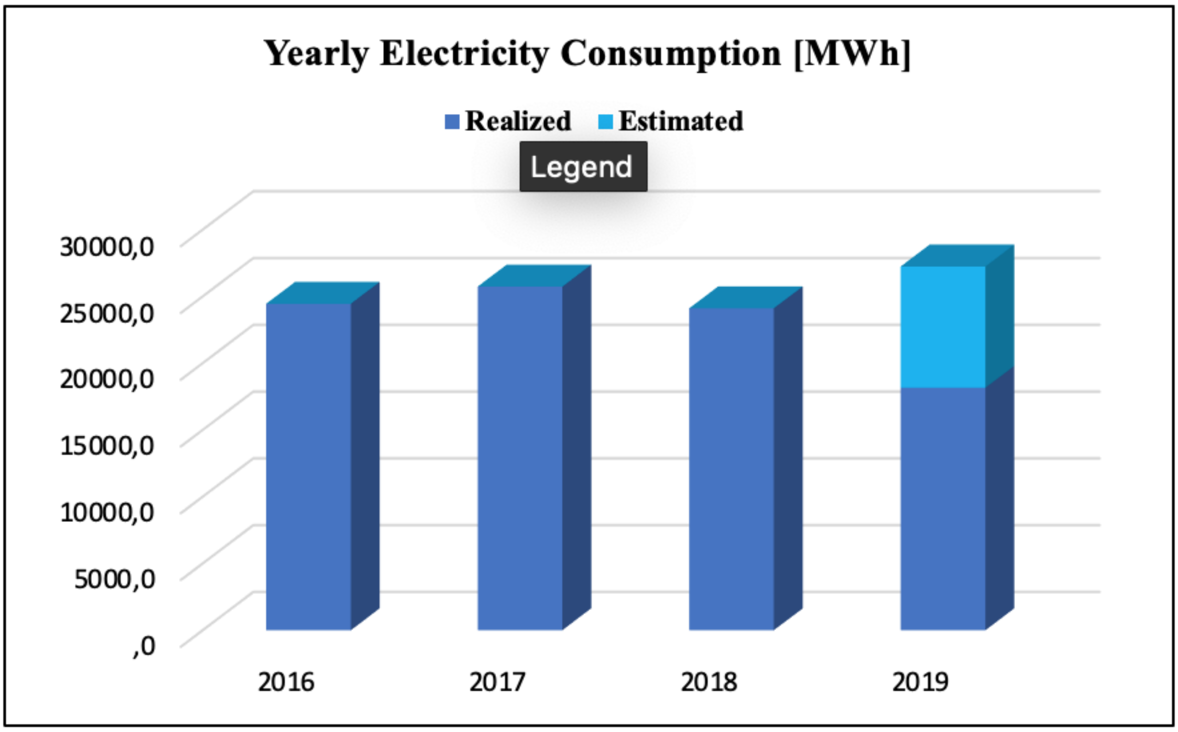


Figure 2: Yearly energy consumption graph

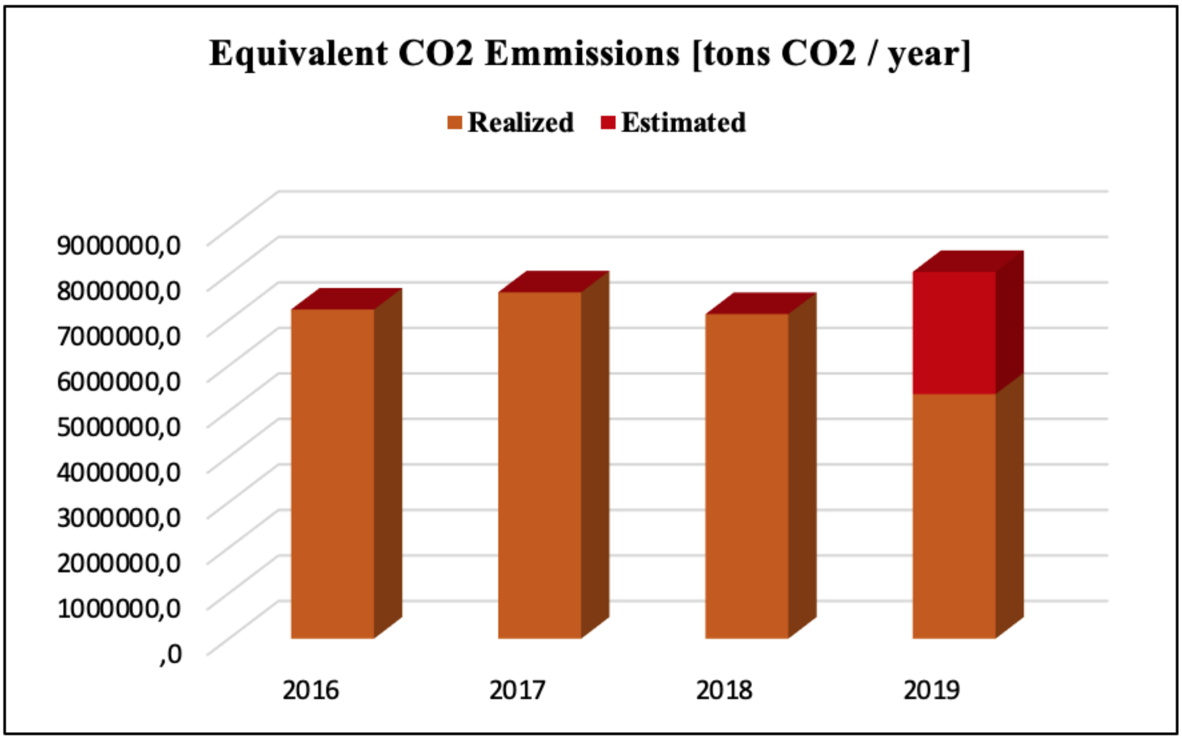


Figure 3: Electrical energy consumption table

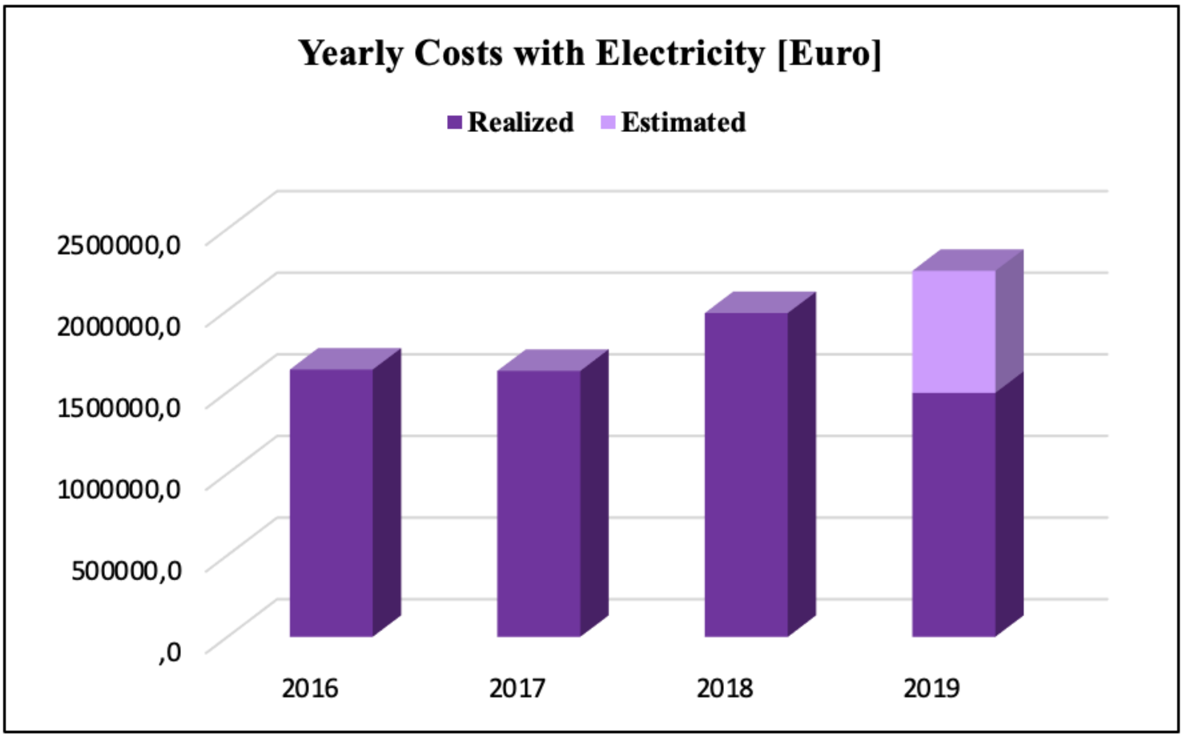


Figure 4: Yearly costs with electricity

Beside the aforementioned graphs, the main feature of the M&T tool is the so called "Monthly electricity and fossil consumption analysis".

Monthly - Electricity - Consumption Analysis							
Select Trend Type:	Linear Function	Start Month:	Jan/ 2016	End Month:	Aug/ 2019	Correlation Coefficient	19,21%

Potential Savings	Electrical Energy Savings				Cost Savings		CO2 Reduction	
Mountly Savings:	24,27	[MWh]	1,07%	[%]	1.998	[Euro]	7.179	[tons CO2]
Yearly Savings	41,24	[MWh]	0,15%	[%]	3.394	[Euro]	12.198	[tons CO2]

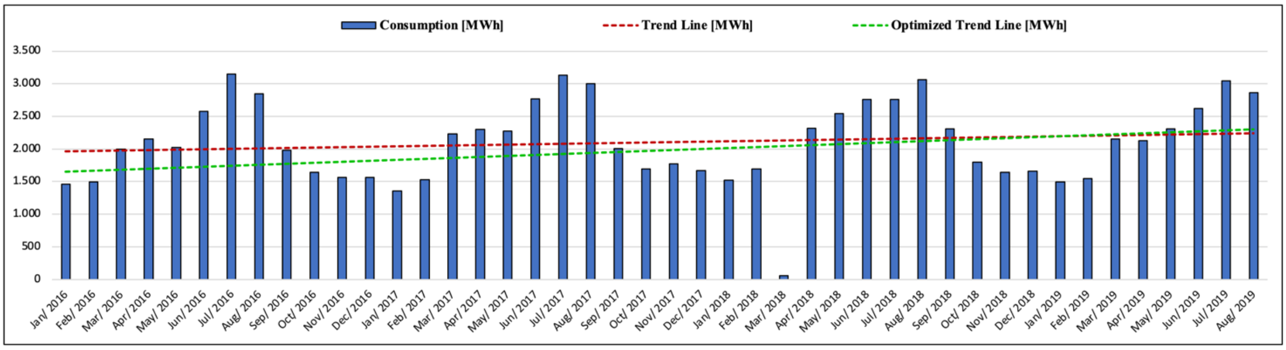


Figure 5: Monthly electricity consumption analysis – linear function

In the monthly consumption analysis area, the user must select the trend type, the time period and the correlation coefficient. After selecting these parameters, the potential savings and the CO2 reduction are calculated automatically along with a graph which depicts the trend line and the optimized trend line. There are 6 different regression models (approximation functions) implemented that will be presented in the following paragraphs as mathematical models. The regression/approximation models are used to obtain a *real* trend line based on the whole available (or selected by the user) data set, and an *optimized* trend line based on 80% of the closest to each other data points of the available (or selected by the user) data set. In Excel the implemented regression/approximation models work on the scaled data values to the selected measurement units.

The evaluated potential savings from the “electricity” and “fossil energy” Excel Sheets could be considered as consumption and/or CO2 emissions reduction targets, if the proper trend line functions are applied (the trend line function that best fits the historical consumption, production data available). These consumption / CO2 emissions reduction targets (potential savings) could be achieved by the SME only by identifying some good practice behaviors in its production history and applies it for their future production, or some bad practice behaviors that should be avoided in the future.

2.2.1. Regression models calculations

The user of the M&T tool can select the type of the regression model. The following types are available: linear, exponential, logarithmic, power, second order polynomial and third order polynomial.

The scope of the regression analysis is to examine the correlation of the dependent variables with the independent ones. In the M&T tool, the dependent variable is the consumption. The independent one is the production. The general relationship between these two is the following:

Consumption = slope x production + intercept

The term "*slope x production*" identifies which part of the consumption is influenced by the production, while the term "*slope*" identifies the level, i.e. the magnitude of this influence. The term "*intercept*" identifies the consumption that is not influenced by the production, i.e. the fixed part of the consumption. The above equation is modeled via a univariate linear model. It assumes that consumption is influenced by one variable. However, assumptions of multivariate models can be also made. The regression analysis aims at the determination of the terms *"slope"* and *"intercept"* based on a given set of pair values of consumption and reduction. Once they have been determined, future consumption values can be drawn using updated production data. In order to provide a detailed analysis, the M&T tool, allows the user to enter apart from linear models, non-linear ones. The two terms *"slope"* and *"intercept"* denote how electrical and thermal energy are consumed in the SME and whether potentials of energy efficiency are present. For instance, if the slope is small, then small changes in the production correspond to small changes to the consumption. On the contrary, if the slope of the line is steep, then a small change to the production, i.e. reduction or increment, will lead to large change in the consumption.

Another feature that is utilized in the analysis is the Cumulative Sum (CUSUM). It shows the deviation of the actual consumption and the expected baseline consumption that can be derived by the regression model. It is calculated over a period. When a change of the consumption is observed, then CUMSUM will exhibit positive or negative value. Thus, the potential energy savings can be tracked. Positive CUMSUM values refer to poor energy savings results. Values close to zero mean that the SME follow the same baseline consumption pattern. Negative values represent successful energy savings over time.

In the M&T tool, the user can select, in the respective column of the "Specific Consumption" sheet, to enter either the electricity consumption, or the thermal consumption. The specific consumption is a KPI. The regression plot consists of two axes, namely the specific consumption and the production. After the selection of the type of the regression model, a regression plot is generated. The plot presents two lines, i.e. the Trend Line and the Optimized Trend Line. The first can be regarded as the old standard, i.e. the relationship between the baseline consumption and the production. The Optimized Trend Line refers to the new target, i.e., the user has set a total of 20% reduction of consumption.

Linear regression is the most common regression model. An example of the linear regression model applied to actual measurements is depicted in Fig.5. It builds a linear relationship between a dependent or target variable and a set of independent or explanatory variables. The explanatory variables influence the values of the dependent variable. Let $Y = (Y_1,\dots,Y_n)$, be the dependent variable where n is the number of elements that consist Y. The univariate linear regression model relates the scalar random variable Y to k other random variables, $x_1, \dots, x_k$, called regressors, as:

$$Y = \beta_0 + x_1\beta_1 + \cdots + x_k\beta_k + \varepsilon \quad (1)$$

where β_0 is the intercept term, and ε is the error term. Equation (1) denotes that the dependent variable Y can be expressed as a linear combination of a set of independent variables $x_1, \dots, x_k$ plus an error term ε. Thus, variable Y is obtained by the sum between a deterministic term and a random noise. Typically, $\varepsilon \sim N(0, \sigma^2)$, i.e., the error term follows a normal distribution N with zero mean and standard deviation σ^2. The variables $\beta_0, \beta_1, \dots, \beta_k$ are estimated from the data. These variables are called regression coefficients. Also, Y is called endogenous variable and $x_1, \dots, x_k$ are called predictors, exogenous or explanatory variables. For any single observation $i = 1, \dots, n$ of the data, equation (1) can be expressed as:

$$Y_i = \beta_0 + x_{1,i}\beta_1 + \cdots + x_{k,i}\beta_k + \varepsilon_i \quad (2)$$

The error term ε_i expresses the difference between the values Y_i and the model used to represent them, $\sum_{j=1}^{k} \beta_j x_{ij}$. The model of equation (2) can be expressed in matrix form:

$$\boldsymbol{Y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon} \quad (3)$$

where:

$$\boldsymbol{Y} = \begin{vmatrix} Y_1 \\ \vdots \\ Y_i \end{vmatrix}, \boldsymbol{X} = \begin{bmatrix} 1 & x_{1,1} & \cdots & x_{1,n} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{i,1} & \cdots & x_{l,n} \end{bmatrix}, \boldsymbol{\beta} = \begin{vmatrix} \beta_0 \\ \vdots \\ \beta_n \end{vmatrix}, \boldsymbol{\varepsilon} = \begin{vmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_i \end{vmatrix}$$

The scope is to estimate matrix $\boldsymbol{\beta}$. One common method for the estimation of is the Ordinary Least Squares Algorithm (OLSA). The estimation is held via the error minimization:

$$\varepsilon = \sum_{i=1}^{n} Y_i - (x''_i \beta) \quad (4)$$

The above equation can be rewritten as:

$$\varepsilon = Y^T Y - Y^T X\beta - \beta X^T Y + \beta^T X^T X\beta \quad (5)$$

The error minimization is done through the following condition:

$$\frac{\partial \varepsilon}{\partial \beta} = 0 = \beta^T X^T X - Y^T X \quad (6)$$

The solution of the equation (6) is:

$$\beta = (X^T X)^{-1} X^T Y \quad (7)$$

Let $\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$ and $\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$ be the means of Y and X. Intercept β_0 is given by the following equation:

$$\beta_0 = \bar{Y} - \beta\bar{X} \quad (8)$$

Let SYY and SXX be the sums of squares of Y and X, respectively. They are expressed as:

$$SYY = \sum_{i=1}^{n}(Y_i - \bar{Y})^2 = \sum_{i=1}^{n}(Y_i)^2 - n\,\bar{Y}^2 \quad (9)$$

$$SXX = \sum_{i=1}^{n}(X_i - \bar{X})^2 = \sum_{i=1}^{n}(X_i)^2 - n\,\bar{X}^2 \quad (10)$$

The sum of cross products is SXY is given by:

$$SXY = \sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y}) = \sum_{i=1}^{n} X_i Y_i - n\,\bar{Y}\bar{X} \quad (11)$$

The following equation is equivalent to equation (7):

$$\beta = \frac{SXY}{SXX} \tag{12}$$

The exponential regression model is the second type of regression analysis employed in this tool. An application of this model is depicted in the following Figure.

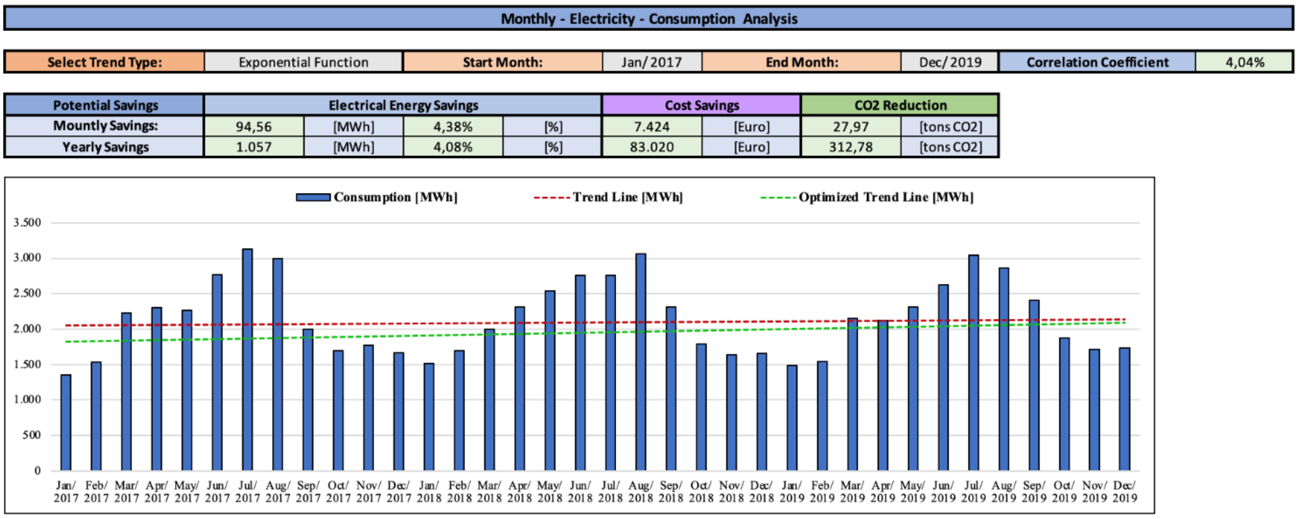


Figure 6: Monthly electricity consumption analysis – exponential function

The exponential regression model is based on the following equation:

$$Y = \beta_0 e^{\beta x} \tag{13}$$

In this case, it is:

$$\beta_0 = e^{\ln(\bar{Y} - \beta\bar{X})} \tag{14}$$

Coefficients β are calculated as:

$$\beta = \frac{SXY}{SXX} = \frac{\sum_{i=1}^{n} X_i \ln(Y_i) - n\bar{Y}\ln(\bar{X})}{\sum_{i=1}^{n}(X_i)^2 - n\bar{X}^2} \tag{15}$$

The third type of regression model used in this tool, is the logarithmic model which can be expressed by the following equation:

$$Y = \beta_0 + \beta \ln(x) \tag{16}$$

Intercept β_0 is: $\beta_0 = \bar{Y} - \beta \ln(\bar{X})$

Coefficients β are calculated as:

$$\beta = \frac{SXY}{SXX} = \frac{\sum_{i=1}^{n} \ln(X_i Y_i) - n\ln(\bar{X}\bar{Y})}{\sum_{i=1}^{n}(\ln(X_i))^2 - nln(\bar{X})^2} \tag{17}$$

The relation that the power model is represented with:

$$Y = \beta_0 \beta^x \tag{18}$$

Intercept β_0 is: $\beta_0 = e^{\ln(\bar{Y}) - \ln(\beta\bar{X})}$

Coefficients β are calculated as:

$$\beta = \frac{SXY}{SXX} = \frac{\sum_{i=1}^{n}(\ln(X_i)\ln(Y_i)) - n\ln(\bar{X})\ln(\bar{Y})}{\sum_{i=1}^{n}(\ln(X_i))^2 - n\ln(\bar{X})^2} \tag{19}$$

An example of the logarithmic model used in this tool, is depicted in Fig.7.

Monthly - Electricity - Consumption Analysis							
Select Trend Type:	Logaritmic Function	Start Month:	Jan/2017	End Month:	Dec/2019	Correlation Coefficient	4,11%

Potential Savings	Electrical Energy Savings				Cost Savings		CO2 Reduction	
Mountly Savings:	110,50	[MWh]	5,12%	[%]	8.676	[Euro]	32,69	[tons CO2]
Yearly Savings	1.227	[MWh]	4,74%	[%]	96.320	[Euro]	362,89	[tons CO2]

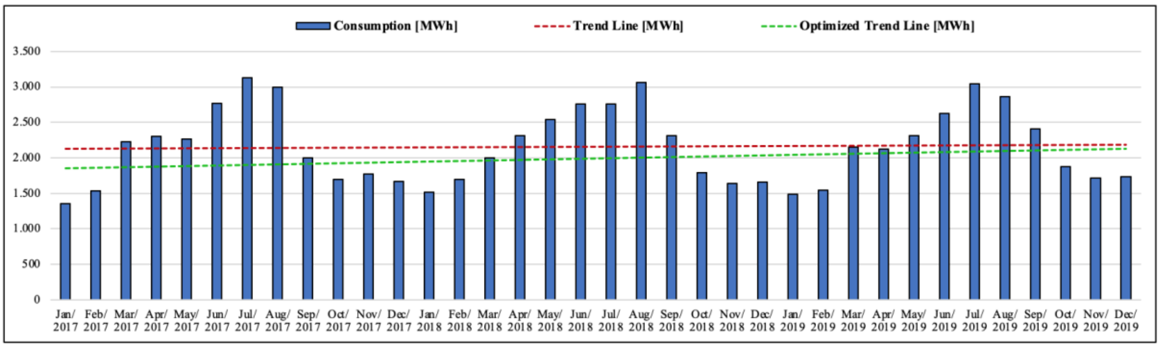


Figure 7: Monthly electricity consumption analysis – logarithmic function

The second order polynomial model is given by:

$$Y = \beta_0 + x_1\beta_1 + \cdots + x_k\beta_k + x_1^2 a_1 + \cdots + x_k^2 a_k + \varepsilon \tag{20}$$

where $a_1, \dots, a_k$ are random variables.

Intercept β_0 is:

$$\beta_0 = \bar{Y} - \beta\bar{X} - a\bar{X}\overline{X^2} \tag{21}$$

where $\overline{X^2} = \frac{1}{n}\sum_{i=1}^{n} X_i^2$.

Coefficients β and a are calculated as, respectively:

$$\beta = \frac{SXYSX^2X^2 - SX^2YSXX^2}{SXXSX^2X^2 - (SXX^2)^2} \tag{22}$$

$$\alpha = \frac{SX^2YSXX - SXYSXX^2}{SXXSX^2X^2 - (SXX^2)^2} \tag{23}$$

where:

$$SXX^2 = \sum_{i=1}^{n}(X_i - \bar{X})(X_i^2 - \overline{X^2}) = \sum_{i=1}^{n}(X_i^3) - n\,\bar{X}\overline{X^2} \tag{25}$$

$$SX^2X^2 = \sum_{i=1}^{n}(X_i^2 - \overline{X^2})^2 = \sum_{i=1}^{n}(X_i^4) - n\,\overline{X^2}\,\overline{X^2} \tag{26}$$

$$SX^2Y = \sum_{i=1}^{n}(X_i^2 - \overline{X^2})(Y_i - \bar{Y}) = \sum_{i=1}^{n}(X_i^2 Y_i) - n\,\overline{X^2}\bar{Y} \tag{27}$$

The last type of regression model used in the tool, is the third order polynomial model, it is given by the following equation, and an application of this model is visible in Fig.8:

$$Y = \beta_0 + x_1\beta_1 + \cdots + x_k\beta_k + x_1^2 a_1 + \cdots + x_k^2 a_k + x_1^3 c_1 + \cdots + x_k^3 c_k + \varepsilon \quad (28)$$

where $c_1, \ldots, c_k$ are random variables. The coefficients are calculated accordingly.

The evaluation of the performance of the models is held with the following indicators:

- Coefficient of correlation or R^2:

$$R^2 = 1 - \frac{RSS}{SYY} \quad (29)$$

where RSS is the residual sum of squares, which is expressed as:

$$RSS = \varepsilon^2 \quad (30)$$

- Adjusted coefficient of correlation, R^2_{adj}:

$$R^2_{adj} = 1 - \left[\frac{(1-R^2)(i-1)}{p-i-1}\right] \quad (31)$$

where p is the number of variables excluding the constant term β [1]-[3].

Monthly - Electricity - Consumption Analysis							
Select Trend Type:	Third Order Polynomial	Start Month:	Jan/2017	End Month:	Dec/2019	Correlation Coefficient	4,81%

Potential Savings	Electrical Energy Savings				Cost Savings		CO2 Reduction	
Mountly Savings:	235,01	[MWh]	10,89%	[%]	18.451	[Euro]	69,51	[tons CO2]
Yearly Savings	2.241	[MWh]	8,65%	[%]	175.935	[Euro]	662,85	[tons CO2]

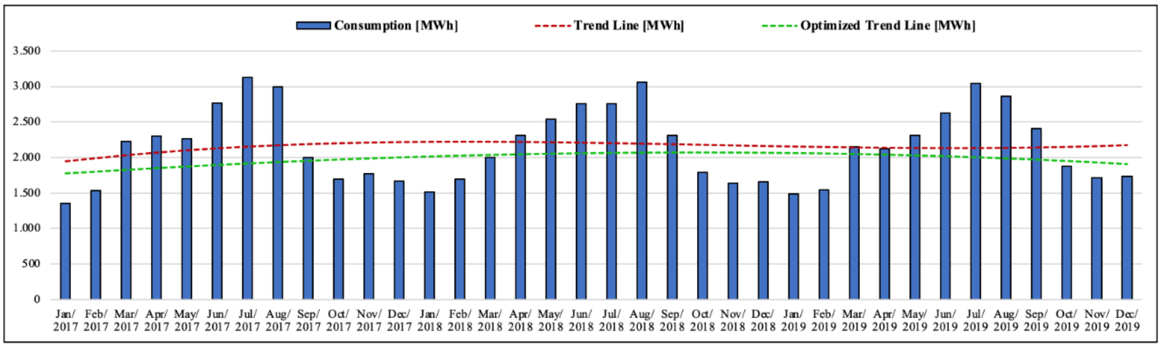


Figure 8: Monthly electricity consumption analysis – third order polynomial

2.2.2. Potential savings calculations

In both the “electricity” and “fossil energy” sheets, the absolute value of the monthly potential savings value is determined as an arithmetic average between the average *real* vs *optimized* trend line value difference over the entire available data set (selected data range) and the consumption difference between the consumption predicted/provided by the *real* and the *optimized* trend lines for the upcoming next month (last month + 1 of the available/selected data range):

$$MSave = \frac{AvgMDiff + NextMDiff}{2} \quad (32)$$

where:

$$AvgMDiff = \frac{1}{N} \cdot \sum_{i=1}^{N} [RealTrend(X_i) - OptTrend(X_i)] \quad (33)$$

$$NextMDiff = RealTrend(X_{N+1}) - OptTrend(X_{N+1}) \quad (34)$$

where:

- $MSave$ – is the absolute value of the monthly potential savings
- $AvgMDiff$ – is the average value of the consumption difference between the consumption predicted/provided by the *real* and the *optimized* trend lines for each month from the investigated (selected) data set / data range.
- $NextMDiff$ – is the difference between the consumption predicted/provided by the *real* and the *optimized* trend lines for the upcoming month (last month + 1 from the available/selected data range/set)
- $RealTrend(\boldsymbol{x})$ – is the output (consumption) value provided by the *real* trend line for a given $\boldsymbol{x}$ input value.
- $OptTrend(\boldsymbol{x})$ – is the output (consumption) value provided by the *optimized* trend line for a given $\boldsymbol{x}$ input value.

2.3. Total consumption sheet

In the total consumption sheet, the total monthly consumption is calculated by converting the electricity and fossil energy to a single unit in order to be able to aggregate them. The table which calculates the aggregated amount is depicted in the following Figure:

Consumption Type:	Total Consumption	Unit	[toe]	Cost In	[Euro]

Monthly - Total Consumption								
Month	2019		2018		2017		2016	
	Amount	Cost	Amount	Cost	Amount	Cost	Amount	Cost
	[toe]	[Euro]	[toe]	[Euro]	[toe]	[Euro]	[toe]	[Euro]
January	473	231.013	463	185.624	496	186.966	485	202.123
February	455	225.426	522	233.186	493	192.545	492	204.663
March	645	318.895	618	278.404	612	248.144	630	265.902
April	572	291.505	621	301.028	614	250.921	585	257.898
May	597	351.505	654	322.632	576	240.053	555	237.473
June	626	379.116	725	354.706	705	289.570	615	278.435
July	708	429.116	717	353.858	762	322.007	750	340.221
August	685	411.007	766	385.525	746	313.932	666	303.891
September	627	275.634	560	289.263	496	213.579	470	215.652
October	527	218.462	469	229.761	468	191.181	441	191.639
November	540	209.410	479	220.846	528	212.213	460	186.415
December	553	214.269	491	226.034	489	198.642	464	186.432
Total	**7.009**	**3.555.360**	**7.086**	**3.380.868**	**6.985**	**2.859.754**	**6.614**	**2.870.744**
Average	584	296.280	591	281.739	582	238.313	551	239.229

Figure 9: Monthly total consumption aggregation

The total aggregated consumption and costs are then plotted in two graphs.

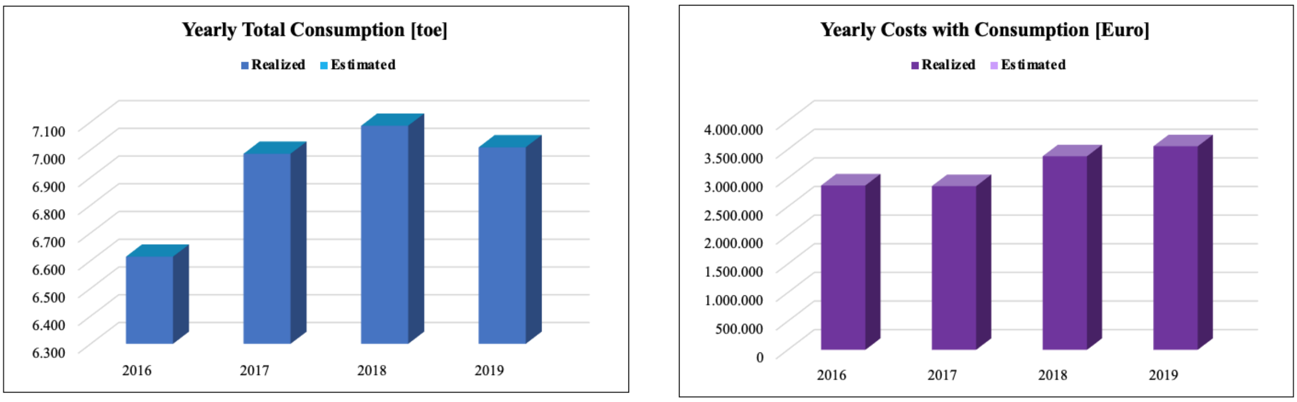


Figure 10: Yearly total consumption and costs

Following the two graphs, the user can select a time period and plot the total monthly consumption per month for the selected time period. The production slope is calculated automatically, as depicted in Fig.11.

Monthly - Total Consumption Analysis					
Start Month	Jan/ 2016	End Month	Dec/ 2019	Production Slope	0,70601

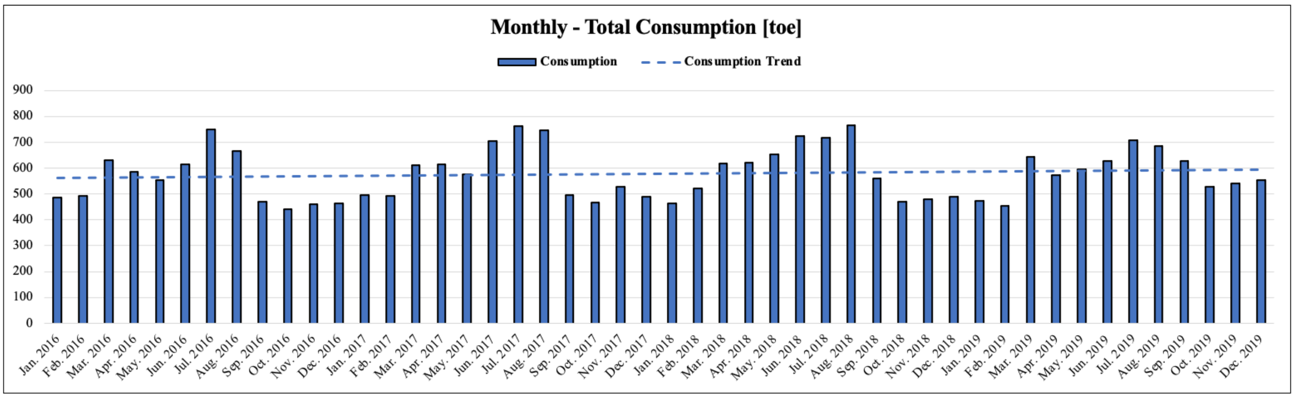
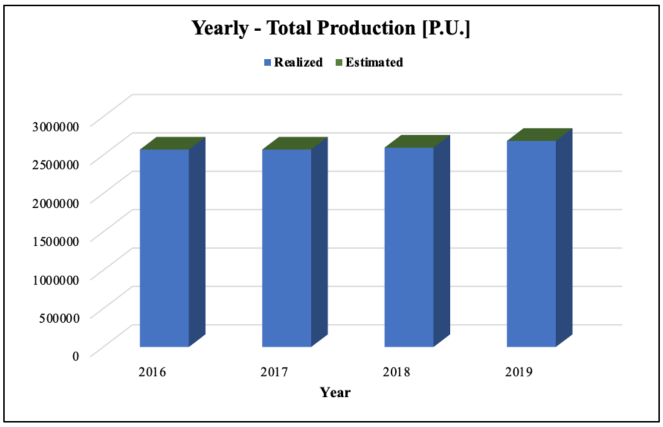


Figure 11: Monthly total consumption analysis

2.4. Production sheet

In this sheet, the aggregated production data analysis is applied in the same manner as in the previous sheet. The data imported in this sheet must be already aggregated to a single unit, as described previously in this document. The aggregation procedure will be taught to the energy experts during the courses.

After the data has been imported, a table and a graph present them in a user-friendly way as depicted in the Fig.12.



Monthly - Total Production				
Month	2019 Quantity [P.U.]	2018 Quantity [P.U.]	2017 Quantity [P.U.]	2016 Quantity [P.U.]
January	116.992	103.604	98.686	98.686
February	152.296	145.671	138.846	138.846
March	202.131	223.745	215.024	215.024
April	244.536	260.090	252.610	252.610
May	295.946	242.778	228.773	228.773
June	314.507	202.131	304.950	304.950
July	305.575	357.424	362.682	362.682
August	345.175	354.981	321.233	321.233
September	214.553	202.131	197.471	197.471
October	176.028	148.662	149.996	149.996
November	156.640	202.131	150.539	150.539
December	160.768	154.237	151.366	151.366
Total	**2.685.147**	**2.597.585**	**2.572.177**	**2.572.177**
Average	223.762	216.465	214.348	214.348

Figure 12: Total yearly production graph and monthly table

Following the graphs, a monthly graph of the total production is plotted, and the slope of the production trend is calculated similarly to the previous paragraph.

Multi Annual Production Analysis								
Start Month	Jan/2017	End Month	Dec/2019	Production Slope	524		0,9987842

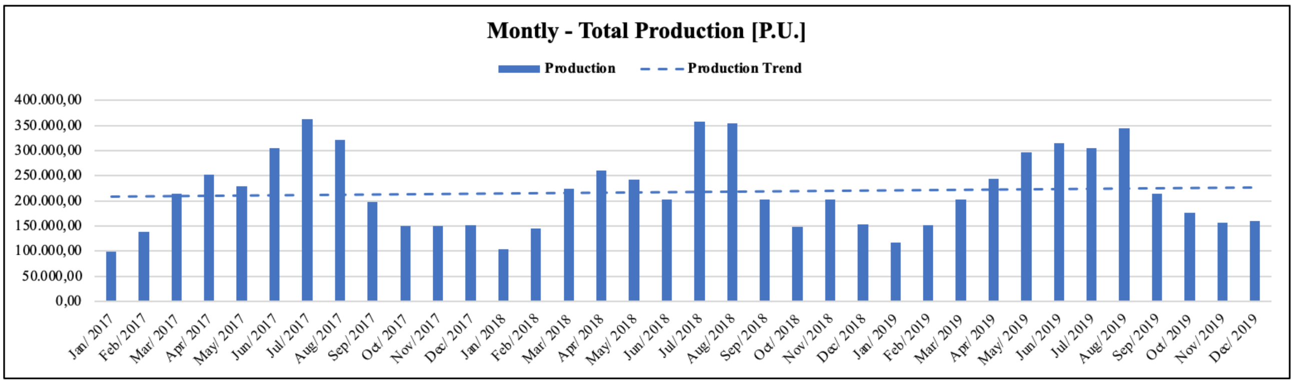


Figure 13: Multi annual production analysis

Below the multi annual production analysis chart, a graph and a small table which compare two consecutive years are presented:

Monthly Production Comaprison

Analysed Year	2019
Reference Year A	2018
Reference Year B	(None)

Yearly Production Increase		
Changes	[P.U.]	[%]
vs Year A	87.562	3,37%
vs Year B	NaN	NaN

Average Monthly Production Increase		
Changes	[P.U.]	[%]
vs Year A	7.297	3,37%
vs Year B	NaN	NaN

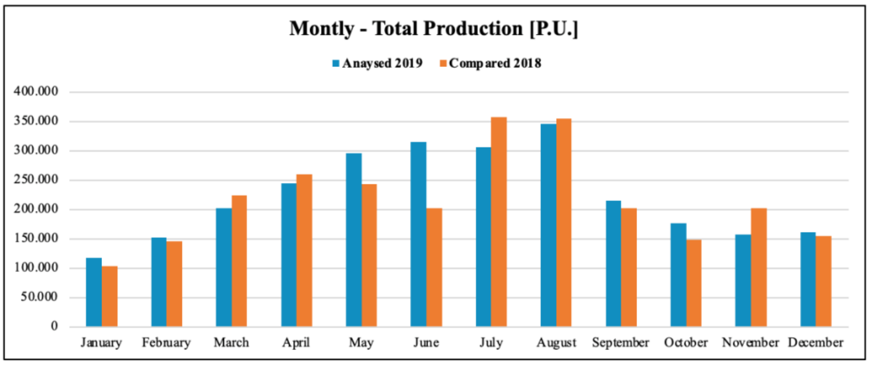


Figure 14: Monthly production analysis

2.5. Specific consumption sheet

In the "*Specific Consumption*" Excel Sheet a more realistic/correct value of the monthly potential savings value is tried to be determined by applying a weighted average based on: the *real* vs *optimized* trend line difference obtained for the predicted/forecasted production value for the upcoming month (last month + 1 of the available/selected data range); the multi annual monthly average *real* vs *optimized* trend line difference value; and monthly average *real* vs *optimized* trend line difference value over the last 12 months of the available/selected data range/set. In the case of the "*Specific Consumption*" Excel Sheets the implemented trend lines will provide/predict the monthly specific consumption value according to the corresponding monthly production.

Monthly - Total Consumption								
Month	2019		2018		2017		2016	
	Amount	Production	Amount	Production	Amount	Production	Amount	Production
	[toe]	[Euro]	[toe]	[Euro]	[toe]	[Euro]	[toe]	[Euro]
January	473	116.992	463	103.604	496	98.686	485	98.686
February	455	152.296	522	145.671	493	138.846	492	138.846
March	645	202.131	618	223.745	612	215.024	630	215.024
April	572	244.536	621	260.090	614	252.610	585	252.610
May	597	295.946	654	242.778	576	228.773	555	228.773
June	626	314.507	725	202.131	705	304.950	615	304.950
July	708	305.575	717	357.424	762	362.682	750	362.682
August	685	345.175	766	354.981	746	321.233	666	321.233
September	627	214.553	560	202.131	496	197.471	470	197.471
October	527	176.028	469	148.662	468	149.996	441	149.996
November	540	156.640	479	202.131	528	150.539	460	150.539
December	553	160.768	491	154.237	489	151.366	464	151.366
Total	**7.009**	**2.685.147**	**7.086**	**2.597.585**	**6.985**	**2.572.177**	**6.614**	**2.572.177**
Average	584	223.762	591	216.465	582	214.348	551	214.348

Monthly - Specific Consumption Analysis - Total Consumption							
Select Trend Type:	Exponential Function	**Start Month:**	Jan/ 2016	**End Month:**	Dec/ 2019	**Correlation Coefficient**	82,15%

Potential Savings	**Electrical Energy Savings**				**Cost Savings**		**CO2 Reduction**	
Mountly Savings:	17,71	[MWh]	10,12%	[%]	NaN	[Euro]	NaN	[tons CO2]
Yearly Savings	NaN	[MWh]	NaN	[%]	NaN	[Euro]	NaN	[tons CO2]

Figure 15: Monthly specific consumption data and analysis

The weighted average is evaluated taking into consideration also the availability of the above-mentioned parameters:

$$MSpCons_D = \frac{(0.5 \cdot NxtM_{SvA} + 0.5 \cdot NxtM_{SvB} + 0.5 \cdot AvgM_{Sv100} + 1 \cdot AvgM_{Sv80} + 2 \cdot LstY_{Avg})}{TWeight} \quad (35)$$

$$MSave = MSpCons_D \cdot MAvgProd \quad (36)$$

where:

- $MSpCons_D$ – is the weighted average specific consumption obtained as a difference between the monthly specific consumption provided by the *real* and the *optimized* trend line functions.
- $MAvgProd$ – is the average monthly production obtained as a weighted value similar to $MSpCons_D$ using the corresponding monthly production values.
- $NxtM_{SvA}$ and $NxtM_{SvB}$ – are is the *real* vs *optimized* trend line difference obtained for the predicted/forecasted production value for the upcoming month (last month + 1 of the

available/selected data range) applying the linear and the nonlinear Excel forecast functions respectively:

$$\boldsymbol{NxtM_{SvA} = RealTrend(NxtMProdA) - OptTrend(NxtMProdA)} \quad (37)$$

$$\boldsymbol{NxtM_{SvB} = RealTrend(NxtMProdB) - OptTrend(NxtMProdB)} \quad (38)$$

with: $NxtMProdA$ and $NxtMProdB$ being the production predicted for the upcoming next month (last month + 1 of the available/selected data range) applying the linear (FORECAST.LINEAR) and the nonlinear (FORCAST.ETS) Excel functions applied to the production data points from the available/selected data range.

- $AvgM_{Sv100}$ and $AvgM_{Sv80}$ – are the multi annual average *real* vs *optimized* trend line difference values considering all the available/selected data set and the closest 80% of data points from a monthly production value point of view:

$$\boldsymbol{AvgM_{Sv100} = \frac{1}{N} \cdot \sum_{i=1}^{N}[RealTrend(X_i) - OptTrend(X_i)]} \quad (39)$$

$$\boldsymbol{AvgM_{Sv80} = \frac{1}{N_{80}} \cdot \sum_{i=1}^{N_{80}}[RealTrend(X_i) - OptTrend(X_i)]} \quad (40a)$$

with: $\boldsymbol{X_i}$ is the i^{th} input value for the implemented *real* and *optimized* trend lines (implemented being the production predicted for the upcoming next month (last month + 1 of the available/selected data range) applying the linear (FORECAST.LINEAR) and the nonlinear (FORCAST.ETS) Excel functions applied to the production data points from the available/selected data range.

- $LstY_{Avg}$ – is the *real* vs *optimized* trend line difference value over the last 12 months of the available/selected data range:

$$\boldsymbol{LstY_{Avg} = \frac{1}{K} \cdot \sum_{i=N-K+1}^{N}[RealTrend(X_i) - OptTrend(X_i)], \ K \leq 12} \quad (40b)$$

with K the number of available data points if there less than 12 data points available in the selected data range, otherwise $K = 12$.

- $TWeigth$ - is the total weight obtained taking into consideration the availability / the possibility to evaluate all the above-mentioned parameters.

1. **Monthly Potential Savings (Percentage Value)**

$$\boldsymbol{MSave\% = \frac{MSave}{AvgMCons} \cdot 100} \quad (41)$$

where:

- $MSave\%$ – is the percentage value of the monthly potential savings
- $AvgMCons$ – is the average monthly consumption over the last year of all the available data points (not restricted to the selected data range)

2. Yearly Potential Savings (Absolute Value)

Potential Savings evaluation in the "Consumption" type Excel Sheets

In the "***Consumption***" type Excel Sheets like „*Electricity*" (and not only) the absolute value of the yearly potential savings value is determined as an arithmetic average between the monthly potential and the consumption difference between the consumption predicted/provided by the *real* and the *optimized* trend lines over the last 12 months from the available/selected data range (or a scaled value of the obtained consumption difference if there are less than 12 available data points):

$$YSave = \frac{12 \cdot MSave + LastYSave}{2} \quad (42)$$

with:

$$LastYSave = \frac{12}{K} \cdot \sum_{i=N-K+1}^{N} [RealTrend(X_i) - OptTrend(X_i)], \;\; K \leq 12 \quad (43)$$

where:

- $YSave$ – is the absolute value of the yearly potential savings
- $LastYSave$ – is the consumption difference between the consumption predicted/provided by the *real* and the *optimized* trend lines for each month over the last year of the available/selected data range.
- K – is the number of available data points if there less than 12 data points available in the selected data range, otherwise $K = 12$.

Potential Savings evaluation in the "Specific Consumption" Excel Sheets

In the "***Specific Consumption***" Excel Sheets the evaluation of the yearly potential savings is not yet implemented (fully functional) but a similar approach as for the "***Consumption***" type Excel Sheets is designed/planed.

3. Yearly Potential Savings (Percentage Value)

$$\boldsymbol{YSave\%} = \frac{\boldsymbol{YSave}}{\boldsymbol{LastYCons}} \cdot \mathbf{100} \quad (44)$$

where:

- $YSave\%$ – is the percentage value of the yearly potential savings
- $LastYCons$ – is the consumption over the last year of all the available data points (not restricted to the selected data range)

4. Cost Savings

The monthly and yearly cost savings are determined by multiplying the absolute monthly or yearly potential savings value with the average specific cost value over the last year of all available data points:

$$MCostSave = MSave \cdot AvgSpCost \quad (45)$$

$$YCostSave = YSave \cdot AvgSpCost \quad (46)$$

$$AvgSpCost = \frac{AvgMCost}{AvgMCons} \quad (47)$$

where:

- $MCostSave$ and $YCostSave$ – are the monetary/cost savings due to consumption reduction over a month or a year respectively.
- $AvgSpCost$ – is the average specific cost over the last year of all available data points obtained by dividing the average monthly cost with the average monthly consumption.
- $AvgMCost$ – is the average monthly cost with the analysed consumption type over the last year of all available data points.

5. CO2 Reduction

The equivalent CO2 reduction is obtained by multiplying the absolute monthly or yearly potential consumption savings with the corresponding CO2 emissions coefficient:

$$CO2MRed = MSave \cdot CO2Coeff \quad (48)$$

$$CO2YRed = YSave \cdot CO2Coeff \quad (49)$$

where:

- $CO2MRed$ and $CO2YRed$ – are the equivalent monthly and yearly CO2 emissions reduction due to reduction in the monthly and yearly consumption respectively.
- $CO2Coeff$ – is CO2 emissions coefficient for the analysed consumption type.

The proper CO2 emissions coefficient is determined taking into consideration the CO2 emissions as [kg CO2] per base unit of the corresponding consumption type and the selected measurement unit for analysed consumption, according to the conversion coefficients presented in the "***Conversion List***" Excel Sheet (conversion coefficients that should or could be adjusted by the user according to the specificity of their country). For example, in case of a 100 [kWh] reduction of the Electricity consumption the equivalent CO2 emission reduction would be:

$$CO2Red = 100\ [kWh] \cdot EmissCoeff \cdot ConvCoff \quad (50)$$

$$CO2Red = 100\ [kWh] \cdot 295.8\ \frac{[kg\ CO2]}{[MWh]} \cdot 10^{-3} \cdot \frac{[MWh]}{[kWh]} = 29.58\ [kg\ CO2] \quad (51)$$

3. Conclusions and further actions

This deliverable presents the second part of the SMEmPower energy analytics tool. The second part of the tool is the Monitoring and Targeting part and it is responsible for providing the energy managers with guidance on the level of energy consumption that is expected to be occurred in a certain time period.

The tools will be updated, after receiving feedback during the SMEmPower E&T courses, which are now ongoing in the first edition in most of the consortium partner countries, by using real data from the selected SMEs pilot sites.

4. References

[1] M.S. Paolella, "Linear Models and Time-Series Analysis", John Wiley & Sons Ltd, New-Jersey, USA, 2019.
[2] S. Weisberg, "Applied linear regression", John Wiley & Sons, Inc, New Jersey, USA, 2005.
[3] A. Gupta, A. Sharma and A. Goel, "Review of regression analysis models", International Journal of Engineering Research & Technology, vol. 6, iss. 8, August 2017, pp. 58-61.