# EN 410
# Energy Management

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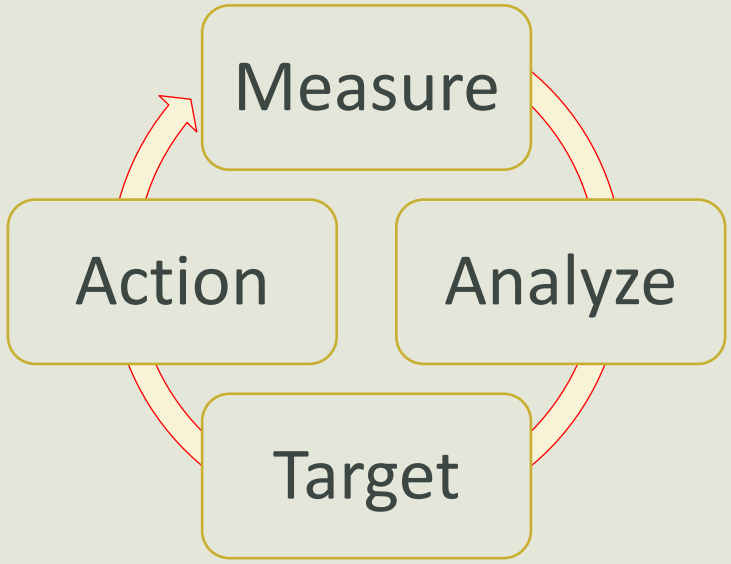
# Recap

- Types of energy auditing
- Steps of detail energy auditing
- Energy conservation measures

# Energy monitoring, targeting and reporting

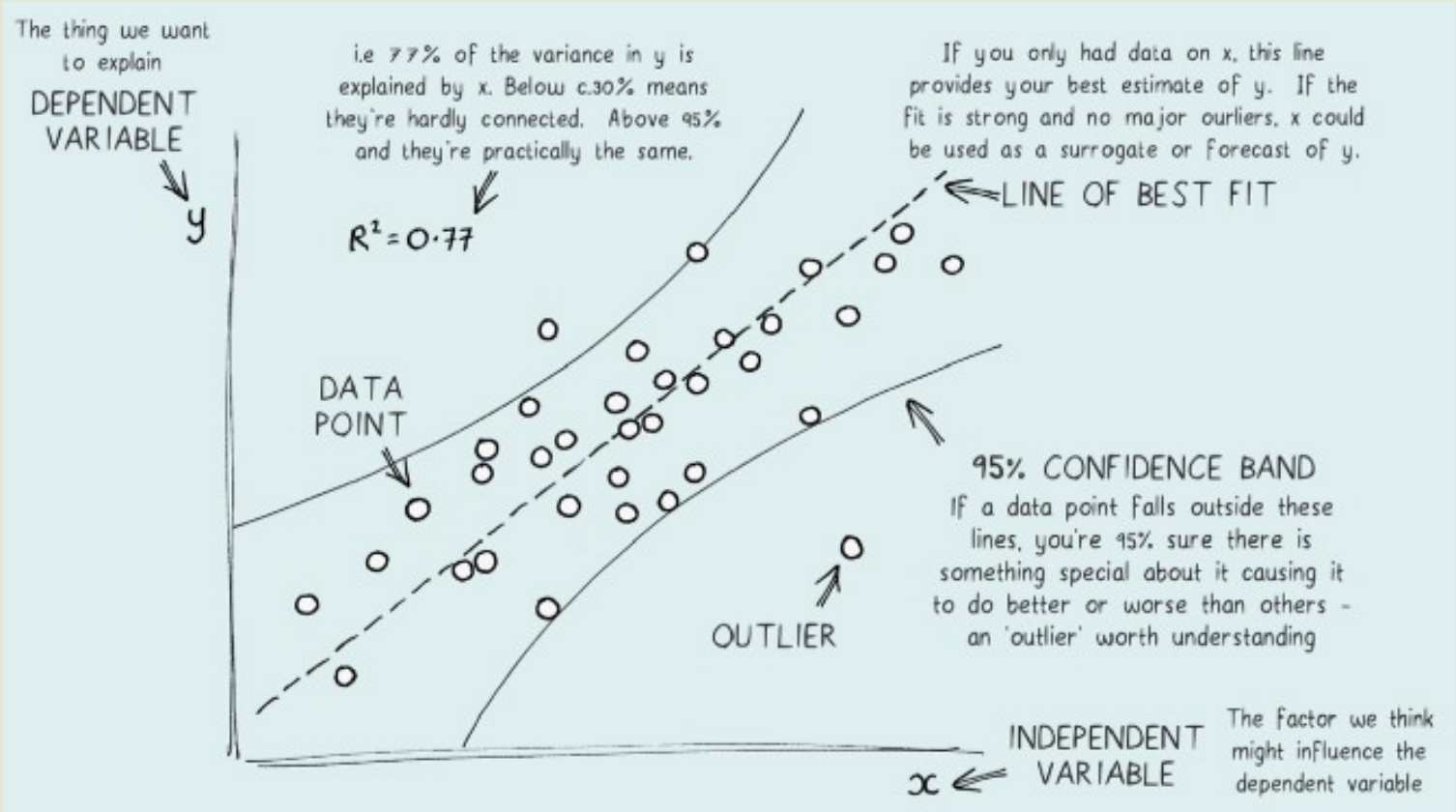
- **Monitoring** - aims at establishing the existing pattern of energy consumption
- **Targeting** - identifies energy consumption level for management to work towards energy conservation
- **Reporting** - ongoing control of energy savings form, achievement of reductions targets and verification of savings
- 5-15% reduction in energy requirement



# Monitoring

- Development of energy performance model – Quantifies the **performance relationship** between the independent variable with the consumption or production
- Methods – Regression or simulation

# What is regression analysis?




$$y = C + mx$$

$$cn + m\Sigma x = \Sigma y$$

$$c\Sigma x + m\Sigma x^2 = \Sigma xy$$

# Example

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Production, Tonnes/month, x | 380 | 440 | 460 | 520 | 320 | 520 | 240 | 620 | 600 |
| Energy use, Toe/month, y | 340 | 340 | 380 | 380 | 300 | 400 | 280 | 424 | 420 |

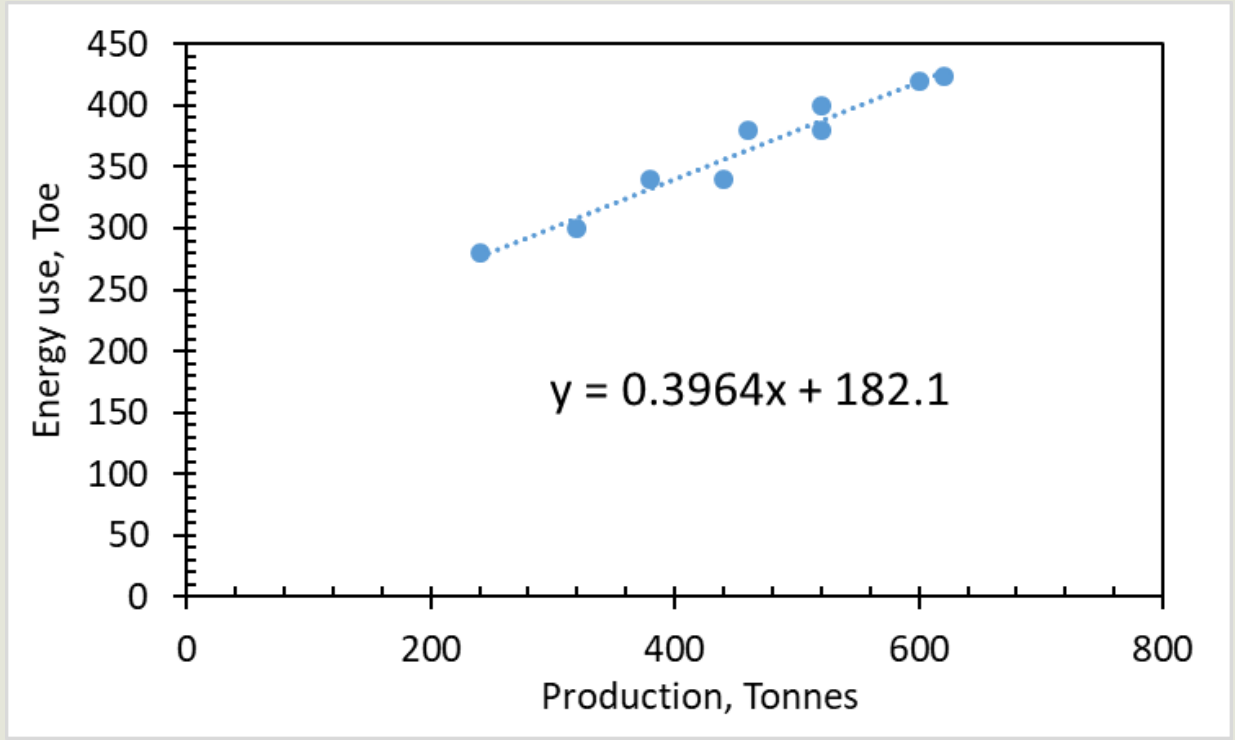
$$y = C + mx$$

$$cn + m\Sigma x = \Sigma y$$

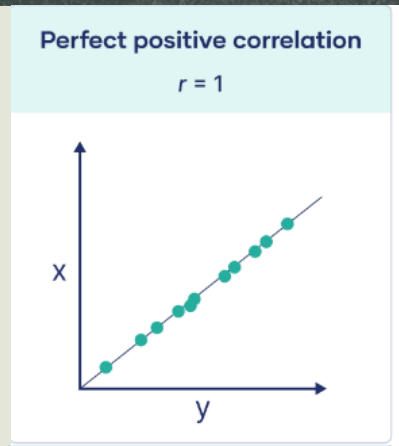
$$c\Sigma x + m\Sigma x^2 = \Sigma xy$$

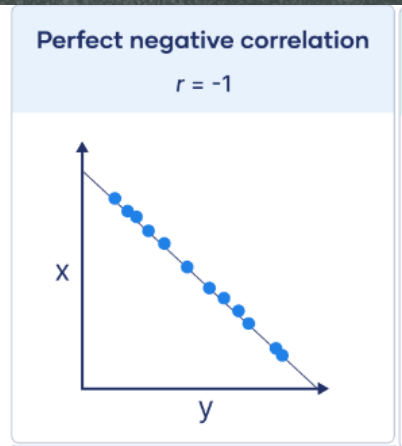
# Regression analysis

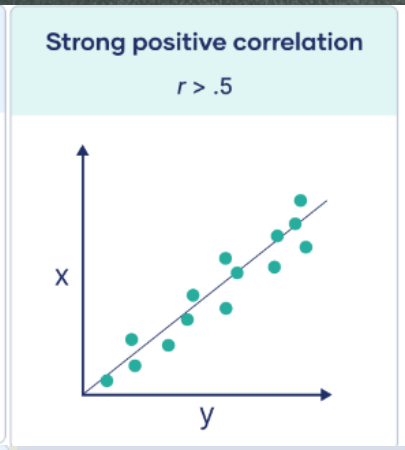
| $n$ | $x$ | $y$ | $x^2$ | $xy$ |
|---|---|---|---|---|
| **1** | 380 | 340 | 144400 | 129200 |
| **2** | 440 | 340 | 193600 | 149600 |
| **3** | 460 | 380 | 211600 | 174800 |
| **4** | 520 | 380 | 270400 | 197600 |
| **5** | 320 | 300 | 102400 | 96000 |
| **6** | 520 | 400 | 270400 | 208000 |
| **7** | 240 | 280 | 57600 | 67200 |
| **8** | 620 | 424 | 384400 | 262880 |
| **9** | 600 | 420 | 360000 | 252000 |
| | **4100** | **3264** | **1994800** | **1537280** |

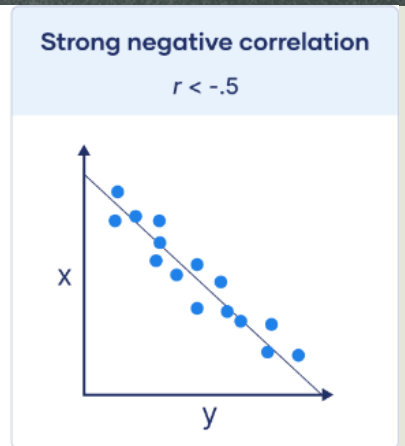


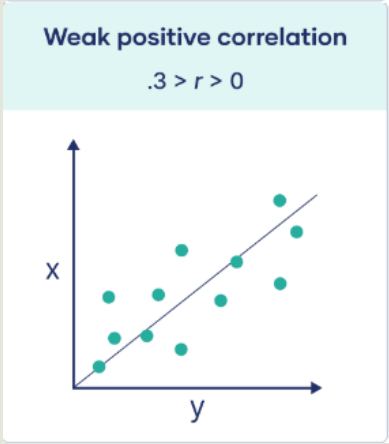
# Pearson correlation coefficient

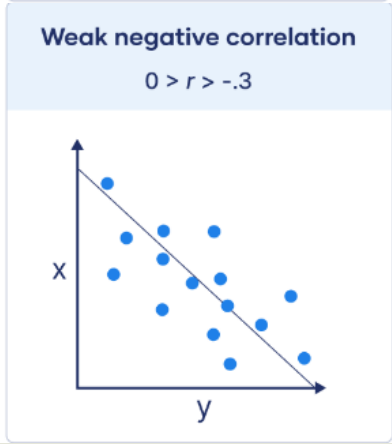


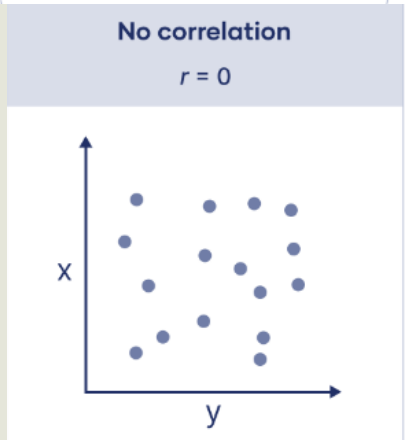




$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

| Number of data | Minimum correlation coefficient |
|---|---|
| 10 | 0.767 |
| 15 | 0.641 |
| 20 | 0.561 |
| 25 | 0.506 |
| 30 | 0.464 |
| 35 | 0.425 |
| 40 | 0.402 |
| 45 | 0.38 |
| 50 | 0.362 |

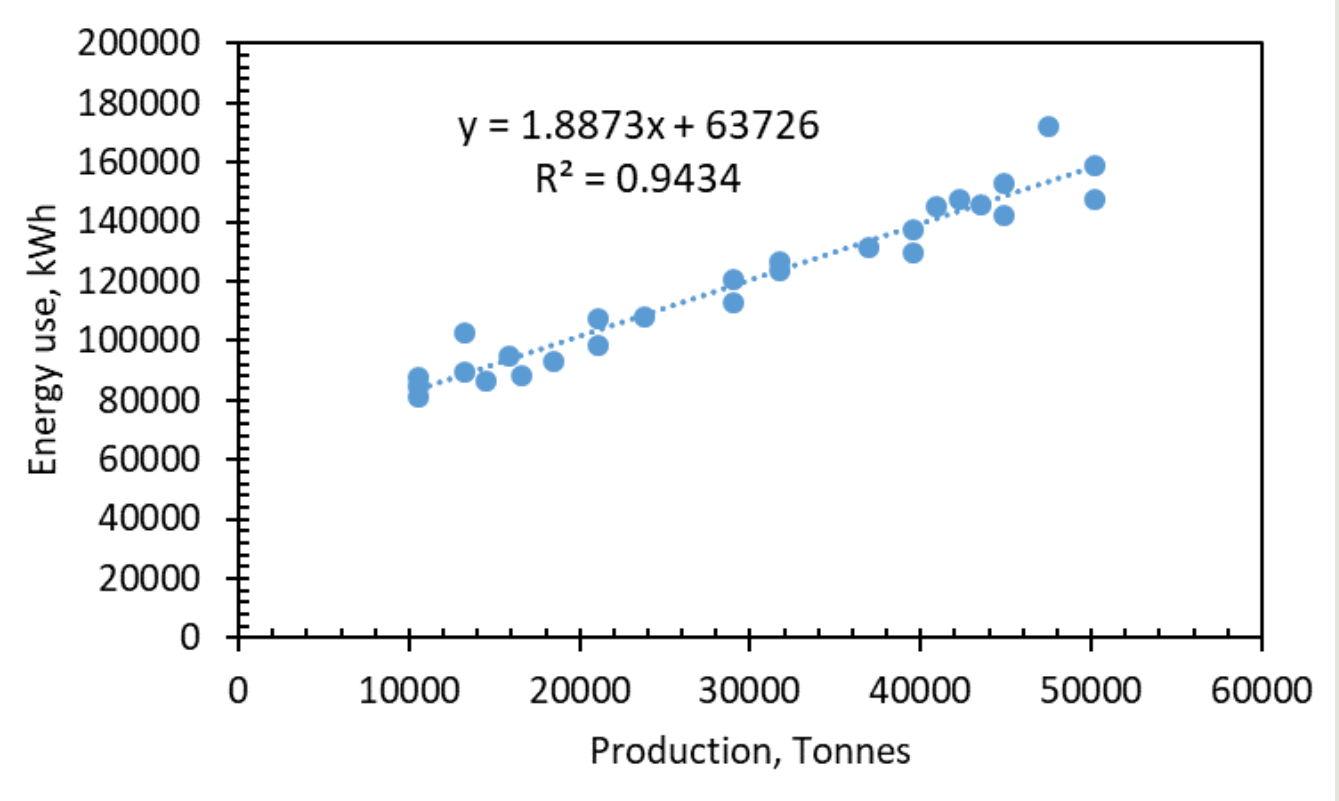
# Pearson correlation coefficient

| $x$ | $y$ | $(x - \bar{x})$ | $(y - \bar{y})$ | $(x - \bar{x})(y - \bar{y})$ | $(x - \bar{x})^2$ | $(y - \bar{y})^2$ |
|---|---|---|---|---|---|---|
| 380 | 340 | -75.56 | -22.67 | 1712.59 | 5708.64 | 513.7778 |
| 440 | 340 | -15.56 | -22.67 | 352.59 | 241.98 | 513.7778 |
| 460 | 380 | 4.44 | 17.33 | 77.04 | 19.75 | 300.4444 |
| 520 | 380 | 64.44 | 17.33 | 1117.04 | 4153.09 | 300.4444 |
| 320 | 300 | -135.56 | -62.67 | 8494.81 | 18375.31 | 3927.111 |
| 520 | 400 | 64.44 | 37.33 | 2405.93 | 4153.09 | 1393.778 |
| 240 | 280 | -215.56 | -82.67 | 17819.26 | 46464.20 | 6833.778 |
| 620 | 424 | 164.44 | 61.33 | 10085.93 | 27041.98 | 3761.778 |
| 600 | 420 | 144.44 | 57.33 | 8281.48 | 20864.20 | 3287.111 |
| **4100** | **3264** | **0** | **0** | **50346.67** | **127022.22** | **20832.00** |

**r = 0.98**

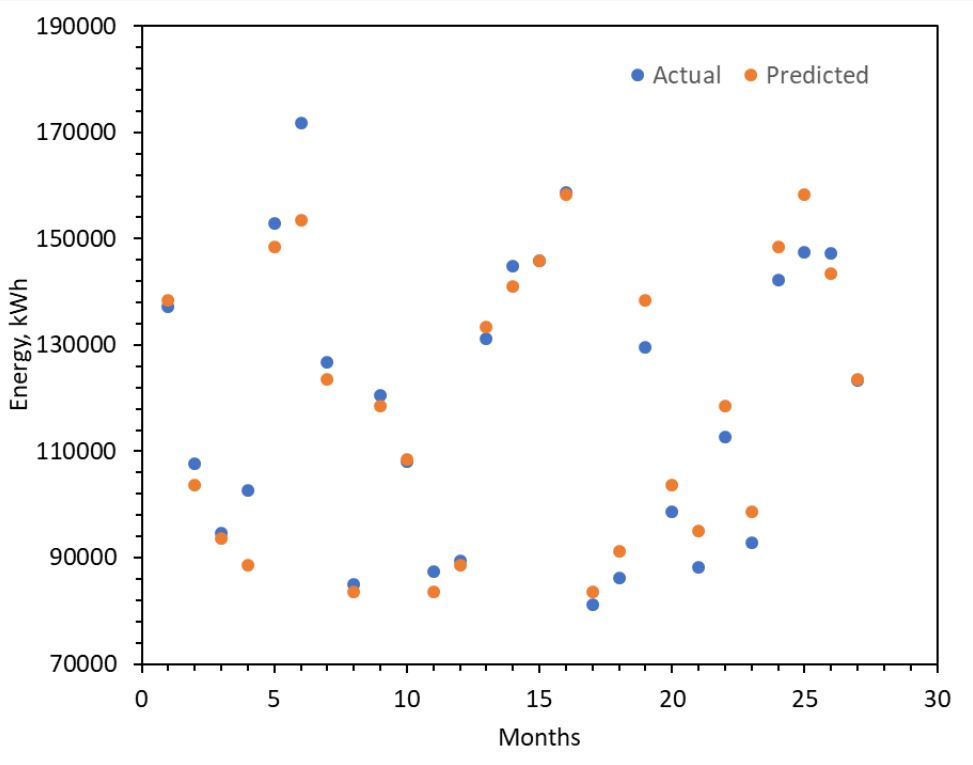
# Energy data of a food processing plant

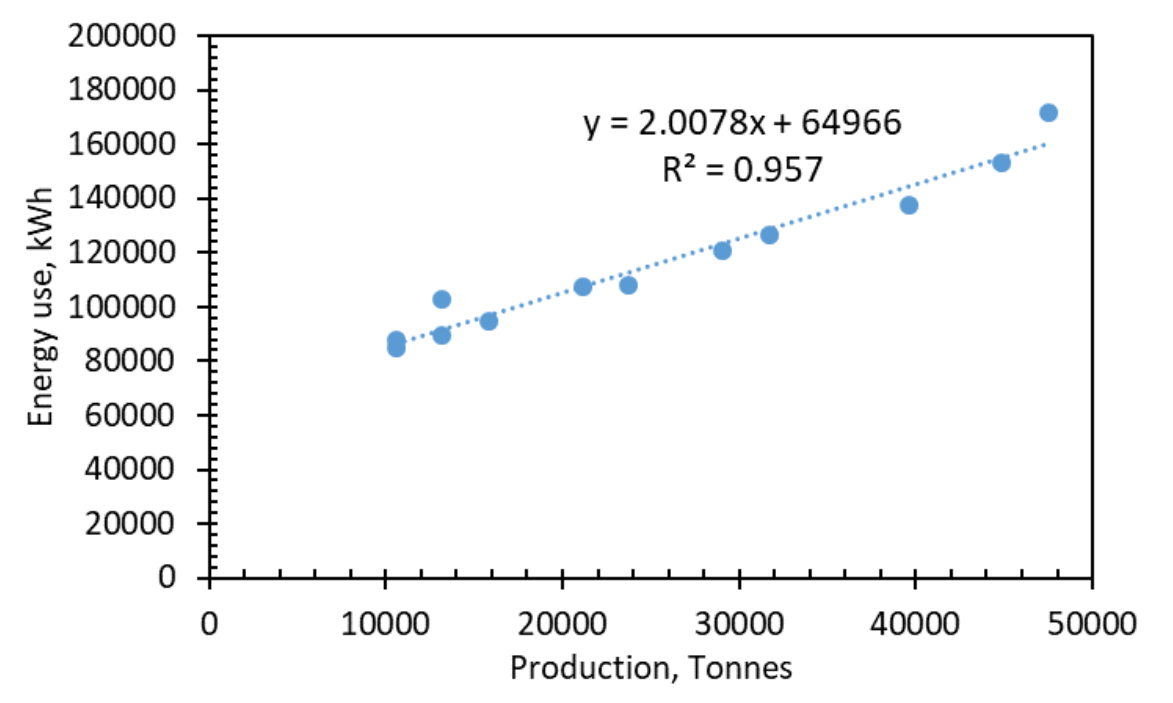
| Month | Production (ton) | Total Process Energy (kWh) |
|---|---|---|
| 1 | 39600 | 137243 |
| 2 | 21120 | 107620 |
| 3 | 15840 | 94630 |
| 4 | 13200 | 102649 |
| 5 | 44880 | 152845 |
| 6 | 47520 | 171792 |
| 7 | 31680 | 126754 |
| 8 | 10560 | 84905 |
| 9 | 29040 | 120510 |
| 10 | 23760 | 108051 |
| 11 | 10560 | 87491 |
| 12 | 13200 | 89379 |
| 13 | 36960 | 131255 |
| 14 | 40920 | 144886 |
| 15 | 43560 | 145882 |
| 16 | 50160 | 158760 |
| 17 | 10560 | 81102 |
| 18 | 14520 | 86234 |
| 19 | 39600 | 129613 |
| 20 | 21120 | 98710 |
| 21 | 16632 | 88233 |
| 22 | 29040 | 112643 |
| 23 | 18480 | 92912 |
| 24 | 44880 | 142198 |
| 25 | 50160 | 147453 |
| 26 | 42240 | 147231 |
| 27 | 31680 | 123359 |



# Energy data of a food processing plant

- Essential to develop the baseline by analyzing the data (not necessarily the first year data..)



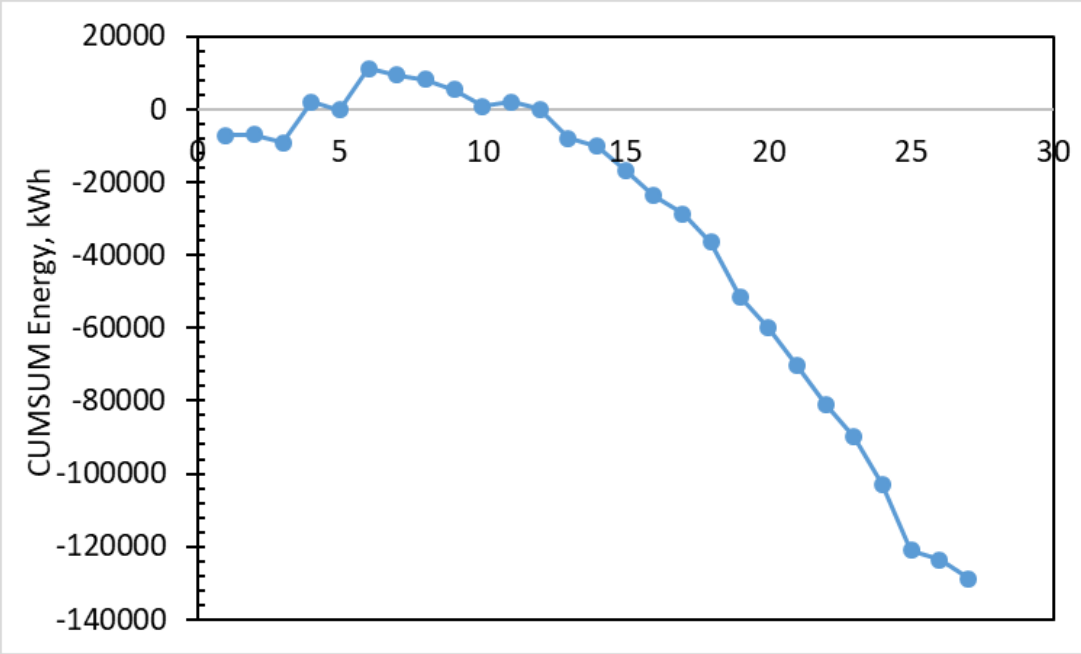



# CUMSUM Analysis

- Cumulative Sum – Difference between baseline (expected/standard) consumption and actual consumption over a period of time
- Provides trend line, Savings/ Losses
- Helps detect impact of energy conservation opportunities, deterioration of plant performance
- Should oscillate around zero after new target

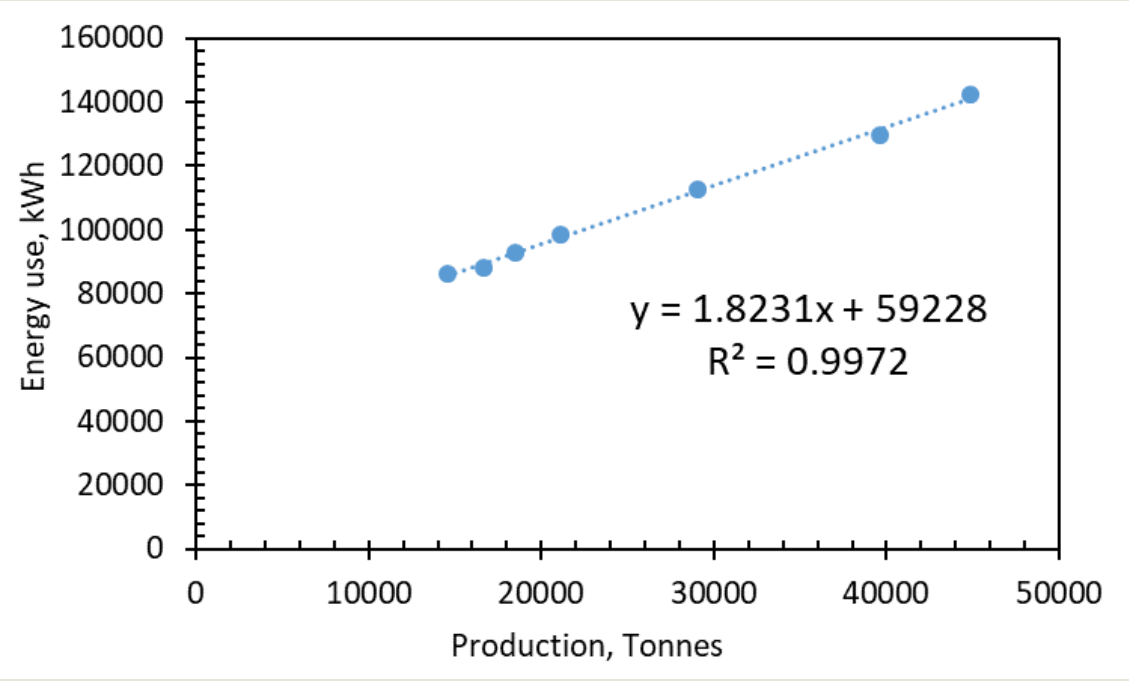
# CUMSUM Analysis

| Month | Production (ton) | Total Process Energy (kWh) | Baseline prediction | Variance | CUMSUM Energy |
|---|---|---|---|---|---|
| 1 | 39600 | 137243 | 144474.9 | -7231.88 | -7231.88 |
| 2 | 21120 | 107620 | 107370.7 | 249.264 | -6982.62 |
| 3 | 15840 | 94630 | 96769.55 | -2139.55 | -9122.17 |
| 4 | 13200 | 102649 | 91468.96 | 11180.04 | 2057.872 |
| 5 | 44880 | 152845 | 155076.1 | -2231.06 | -173.192 |
| 6 | 47520 | 171792 | 160376.7 | 11415.34 | 11242.15 |
| 7 | 31680 | 126754 | 128573.1 | -1819.1 | 9423.048 |
| 8 | 10560 | 84905 | 86168.37 | -1263.37 | 8159.68 |
| 9 | 29040 | 120510 | 123272.5 | -2762.51 | 5397.168 |
| 10 | 23760 | 108051 | 112671.3 | -4620.33 | 776.84 |
| 11 | 10560 | 87491 | 86168.37 | 1322.632 | 2099.472 |
| 12 | 13200 | 89379 | 91468.96 | -2089.96 | 9.512 |
| 13 | 36960 | 131255 | 139174.3 | -7919.29 | -7909.78 |
| 14 | 40920 | 144886 | 147125.2 | -2239.18 | -10149 |
| 15 | 43560 | 145882 | 152425.8 | -6543.77 | -16692.7 |
| 16 | 50160 | 158760 | 165677.2 | -6917.25 | -23610 |
| 17 | 10560 | 81102 | 86168.37 | -5066.37 | -28676.3 |
| 18 | 14520 | 86234 | 94119.26 | -7885.26 | -36561.6 |
| 19 | 39600 | 129613 | 144474.9 | -14861.9 | -51423.5 |
| 20 | 21120 | 98710 | 107370.7 | -8660.74 | -60084.2 |
| 21 | 16632 | 88233 | 98359.73 | -10126.7 | -70210.9 |
| 22 | 29040 | 112643 | 123272.5 | -10629.5 | -80840.4 |
| 23 | 18480 | 92912 | 102070.1 | -9158.14 | -89998.6 |
| 24 | 44880 | 142198 | 155076.1 | -12878.1 | -102877 |
| 25 | 50160 | 147453 | 165677.2 | -18224.2 | -121101 |
| 26 | 42240 | 147231 | 149775.5 | -2544.47 | -123645 |
| 27 | 31680 | 123359 | 128573.1 | -5214.1 | -128859 |




- Analyze the slope
- Best between 18 to 24 months

# Energy consumption data




| Parameter | Baseline | Month 18-24 | % Improvement |
|---|---|---|---|
| Slope (production dependent consumption) | 2.0078 | 1.8231 | 9.2 |
| Intercept (production independent consumption) | 64966 | 59228 | 8.83 |

# CUMSUM Analysis

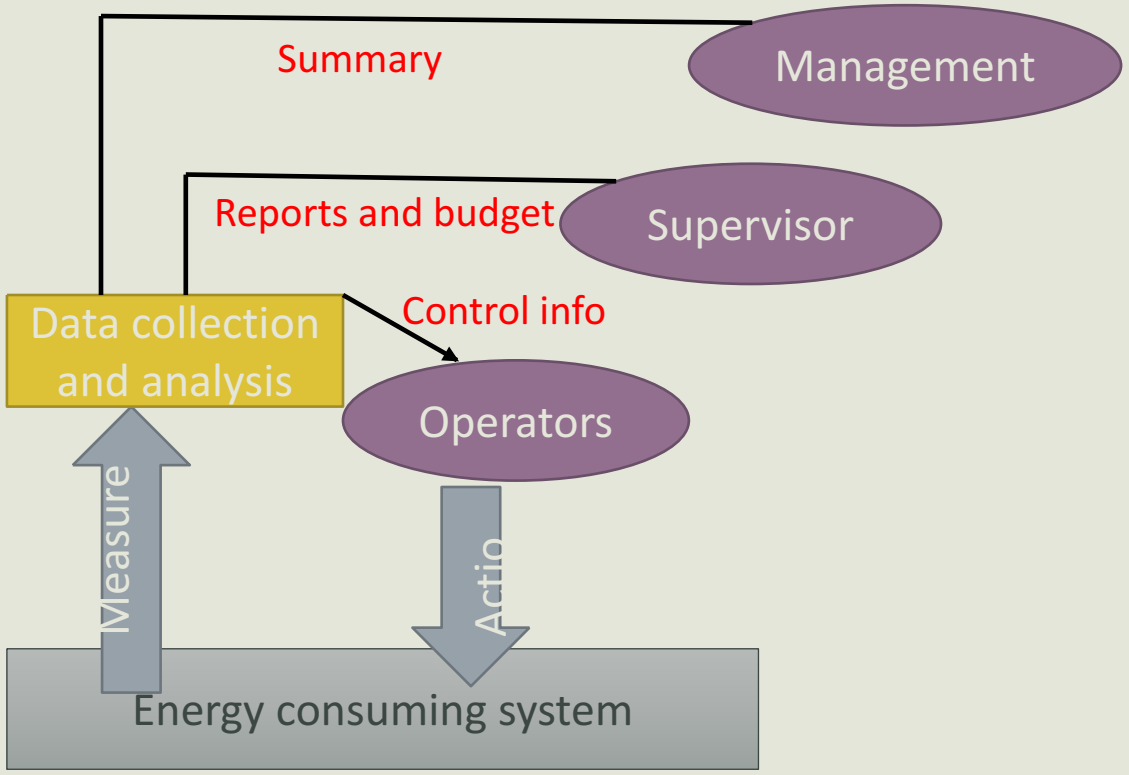
| Month | $E_{act}$ - Monthly Energy Use ( toe * / month) | P - Monthly Production ( tonnes / month) |
|---|---|---|
| 1 | 340 | 380 |
| 2 | 340 | 440 |
| 3 | 380 | 460 |
| 4 | 380 | 520 |
| 5 | 300 | 320 |
| 6 | 400 | 520 |
| 7 | 280 | 240 |
| 8 | 424 | 620 |
| 9 | 420 | 600 |
| 10 | 400 | 560 |
| 11 | 360 | 440 |
| 12 | 320 | 360 |
| 13 | 340 | 420 |
| 14 | 372 | 480 |
| 15 | 380 | 540 |
| 16 | 280 | 280 |
| 17 | 280 | 260 |
| 18 | 380 | 500 |

# Target and control

- Maintain the performance (e.g., 18-24 month)
- Eliminating the highest or least efficient points
- Defining the best from the historical data
- Developing control chart according to the target for each process / equipment / system (= 1.4 times of average variance)

# Reporting

- Essential for mentoring the savings by different level of personnel




| Level | Report frequency | | | |
|---|---|---|---|---|
| Senior management | Annual | Quarterly | | |
| Department head | Annual | | Monthly | |
| EAC manager | Annual | | | Weekly |
| Energy manager | Annual | Quarterly | Monthly | Weekly |

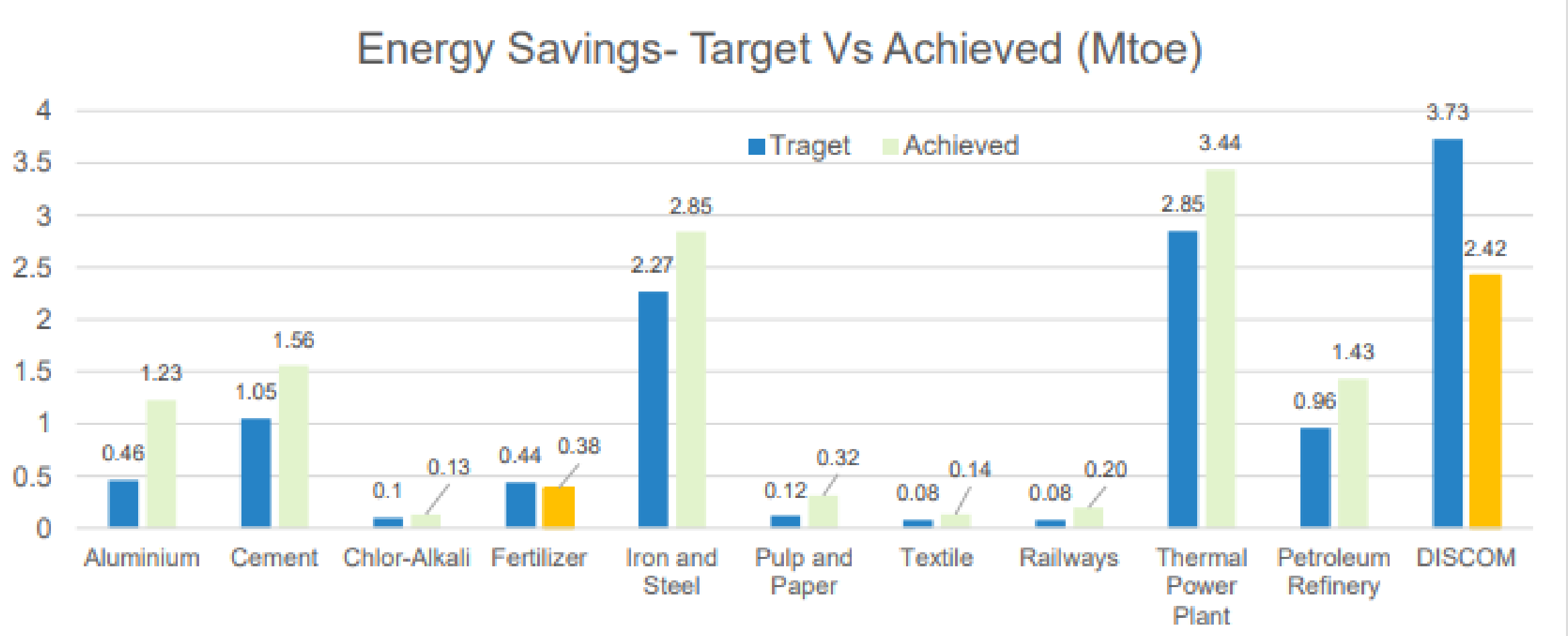
# Energy Benchmarking

- *Energy Benchmark* is the achievable most energy efficient reference point for comparative evaluation
- Highly effective tool for energy efficiency improvements provided comparisons are made on equivalent basis.
- Provides data on how energy is currently used within a particular industrial sector or building type

# Energy Benchmarking

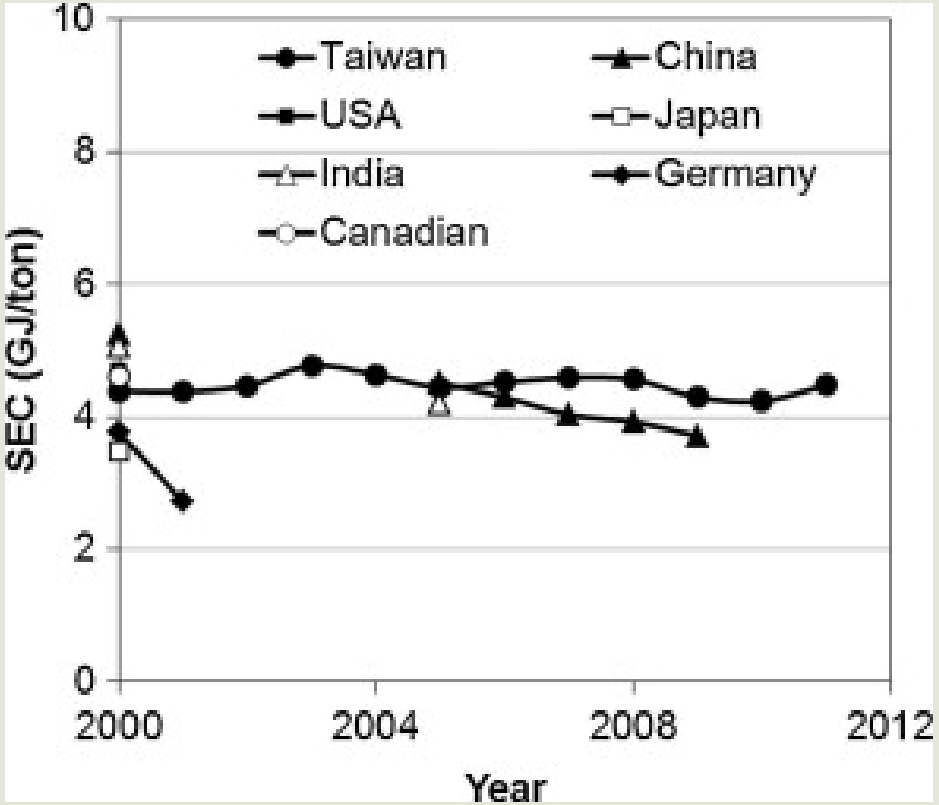
- Industrial Benchmarking types
- Entire industrial sector (for national use)
  - ✓ How much the sector is performing when compared the best technologies
  - ✓ When compared to the other countries
  - ✓ Improvement over time
- Comparing plants within the sector
  - Critical since it contain the proprietary information
  - Comparing within the plants
  - Most used since securing the data

# Energy Benchmarking – Within Country PAT Scheme

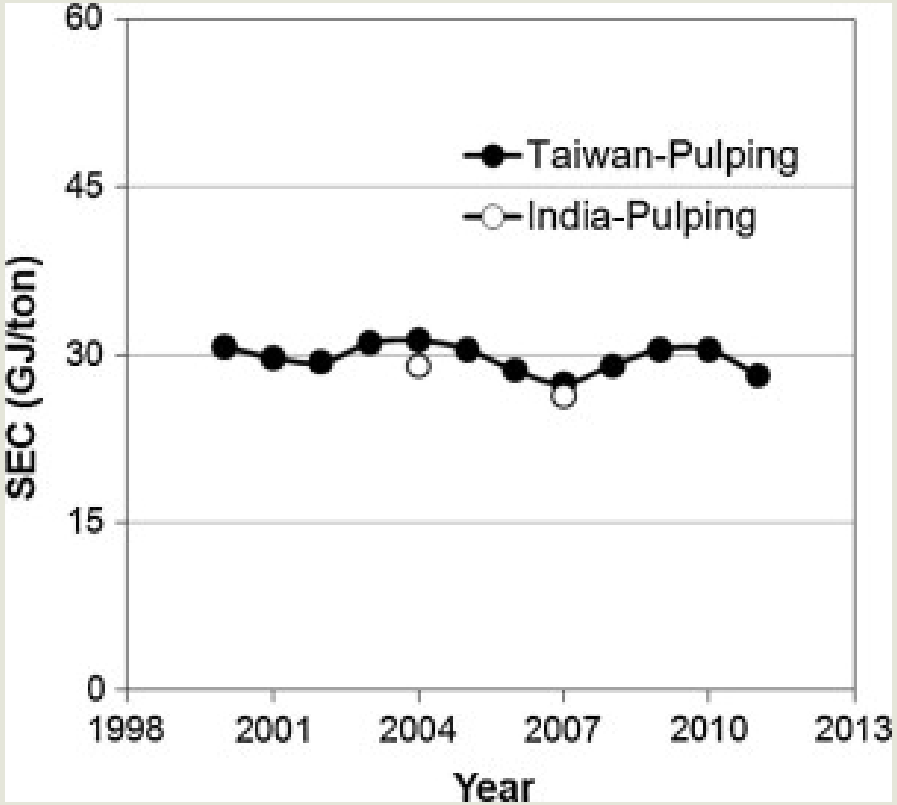


# Energy Benchmarking – Among countries

Energy intensity (SEC) in cement industry




Pulp industry



# Recap

- MT and R process – Elements, steps
- Regression analysis
- CUMSUM Technique
- Energy benchmarking

# Refrences


- https://www.sankey-diagrams.com/engine-efficiency-of-cars/
- https://www.sciencedirect.com/science/article/pii/S0196890413005645#s0015
- https://beeindia.gov.in/sites/default/files/publications/files/Impact%20Assessment%202021-22_%20FINAL%20Report_June%202023.pdf