Environmental Research Institute, University College Cork
Sustainable Energy Research Group
Department of Civil & Environmental Engineering

Modelling energy consumption in a manufacturing plant using productivity KPIs

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eceee Summer Study,
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ucc
Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

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Introduction

- Unit consumption: useful top-down measure of energy efficiency improvements in a manufacturing plant

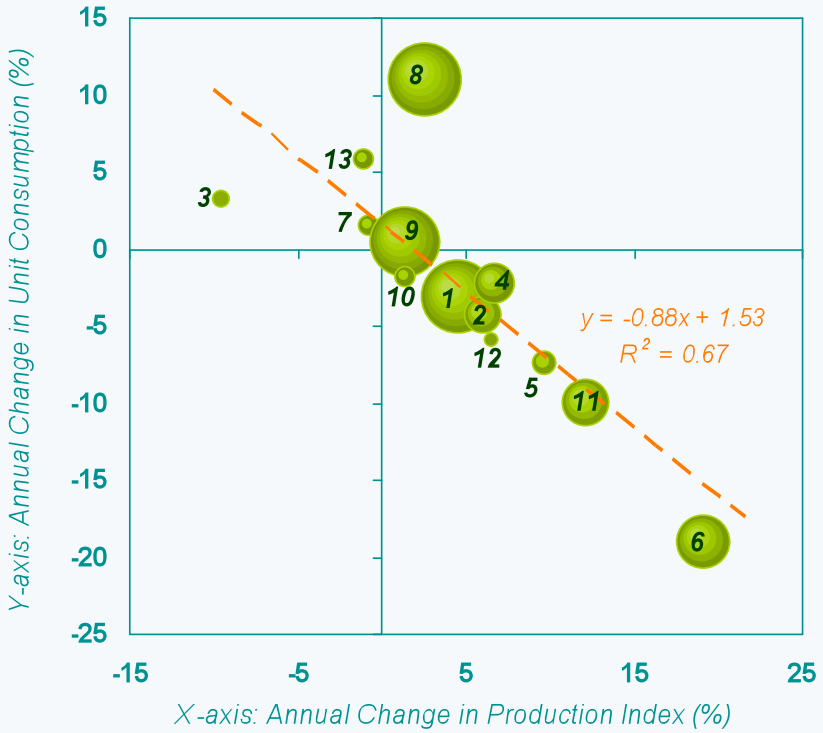
$$UC = \frac{\text{energy consumed}}{\text{production output}}$$

Reduce energy consumption

Increase production output

- Well-established methods for measuring energy consumption and production output
- Alternative approach of measuring productivity using metric from process engineering: OEE

Productivity & Energy Efficiency



1.- NACE 13-14 Mining
2.- NACE 15-16 Food & Beverages
3.- NACE 17-18 Textiles
4.- NACE 20 Wood Products
5.- NACE 21-22 Paper & Publishing
6.- NACE 24 Chemicals
7.- NACE 25 Rubber & Plastic
8.- NACE 26 Non-Metallic Minerals
9.- NACE 27-28 Basic Metals
10.- NACE 29 Machinery & Equipment
11.- NACE 30-33 Electrical & Optical
12.- NACE 34-35 Transport Equipment
13.- NACE 36, 37, 19 Other Manuf.

- Irish Industry: strong relationship between productivity and EE improvements at 2-digit NACE level
- 1% increase in production output -> 0.9% increase in energy efficiency
- Productivity a key driver for EE

What is OEE?

- Overall Equipment Effectiveness
- Measures operating efficiency of machine or line
- Developed by Nakajima (1988) as part of TPM (Total Productive Maintenance)

OEE = %Availability x %Performance x %Quality

- *OEE:* measure of actual output versus max. theoretical output
- *Availablility:* measures losses due to downtime
- *Performance:* measures losses due to plant running at sub-optimal speeds
- *Quality:* measures losses due to poor product or process quality

Calculating OEE

OEE = %Availability x %Performance x %Quality

$$\text{Availability} = \frac{\text{Actual production time}}{\text{Planned production time}}$$

$$\text{Performance} = \frac{\text{Total products / Actual production time}}{\text{Ideal cycle time}}$$

$$\text{Quality} = \frac{\text{Total good products}}{\text{Total products}}$$

Calculating OEE

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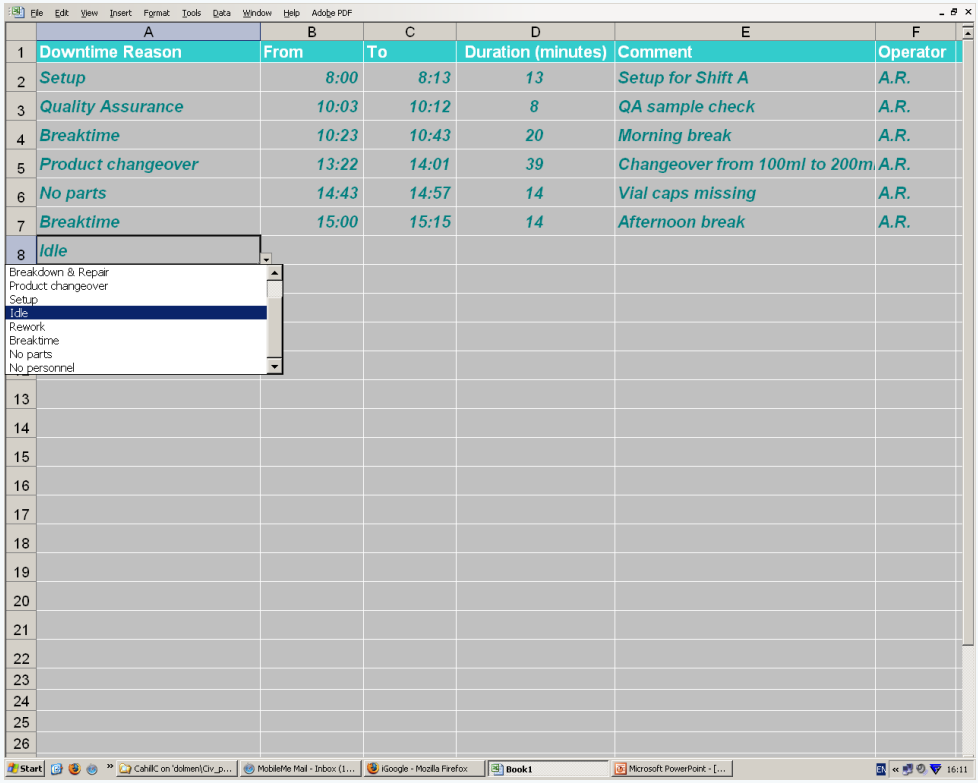
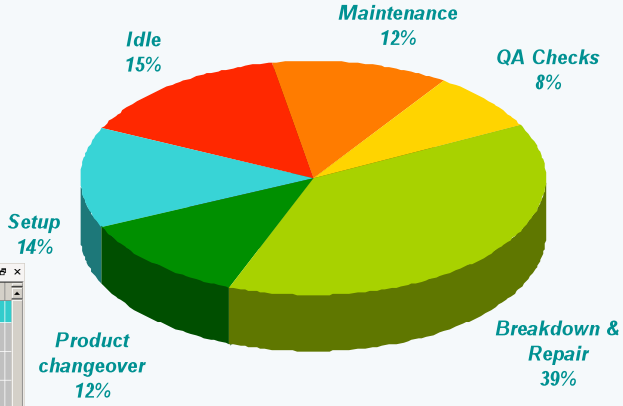
- Reasons for losses can be further detailed using OEE tools



	A	B	C	D	E	F
1	Downtime Reason	From	To	Duration (minutes)	Comment	Operator
2	Setup	8:00	8:13	13	Setup for Shift A	A.R.
3	Quality Assurance	10:03	10:12	8	QA sample check	A.R.
4	Breaktime	10:23	10:43	20	Morning break	A.R.
5	Product changeover	13:22	14:01	39	Changeover from 100ml to 200m	A.R.
6	No parts	14:43	14:57	14	Vial caps missing	A.R.
7	Breaktime	15:00	15:15	14	Afternoon break	A.R.
8	Idle					

Breakdown & Repair
Product changeover
Setup
Idle
Rework
Breaktime
No parts
No personnel



Minimum unit consumption, UC_{min}

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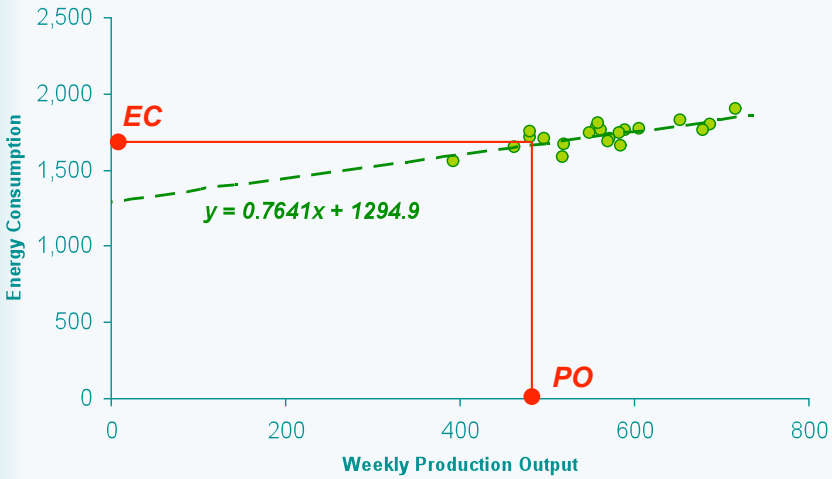
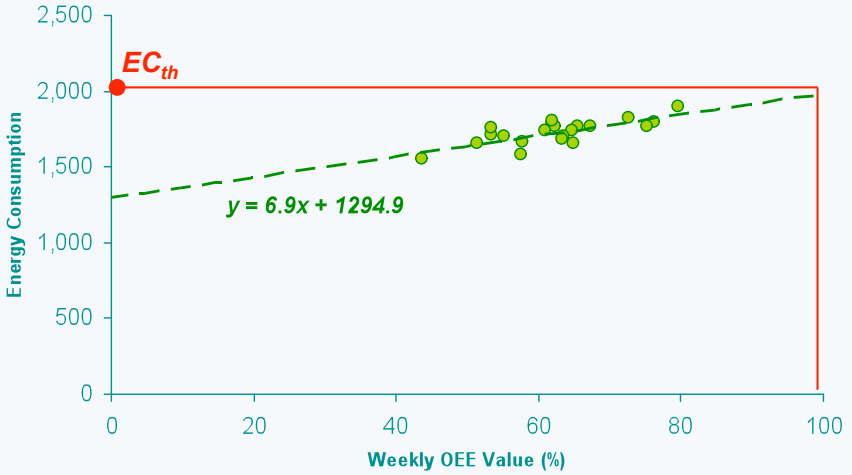
Unit consumption, UC



$$UC = \frac{\text{Energy consumption (EC)}}{\text{Production output (PO)}}$$

Min. unit consumption, UC_{min}

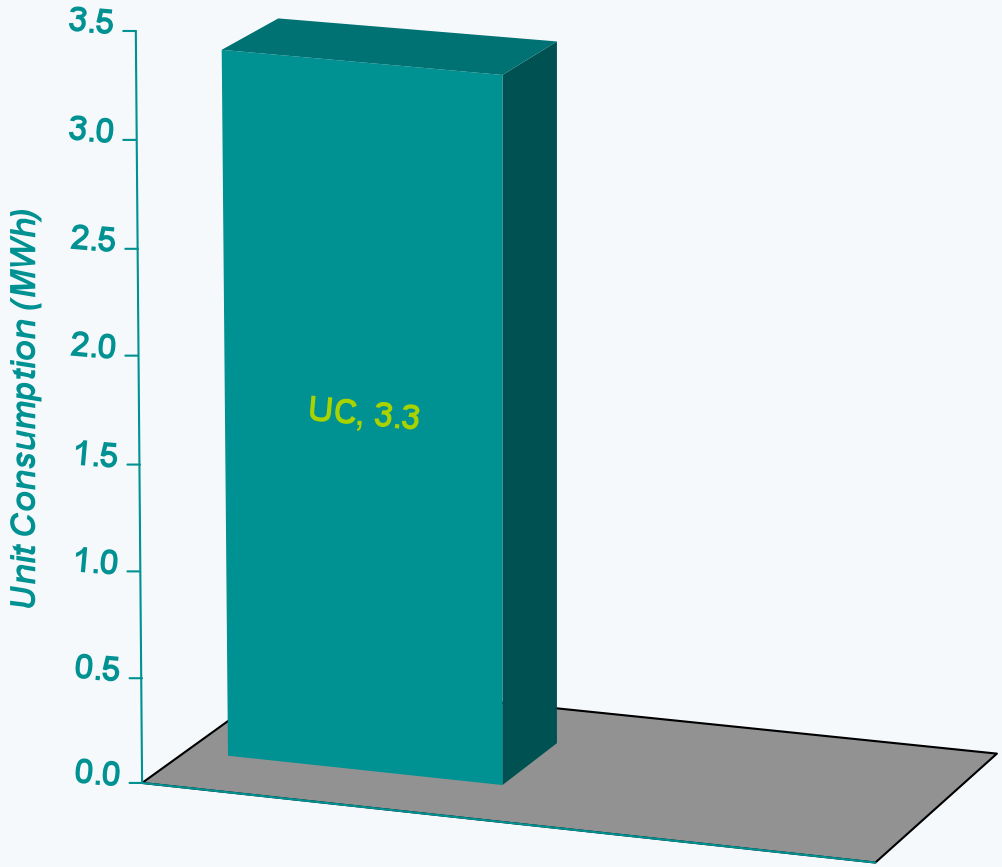


$$\text{Ideal prod. output } (PO_{th}) = \frac{PO}{OEE}$$

$$UC_{min} = \frac{\text{Energy use at } PO_{th} \ (EC_{th})}{PO_{th}}$$

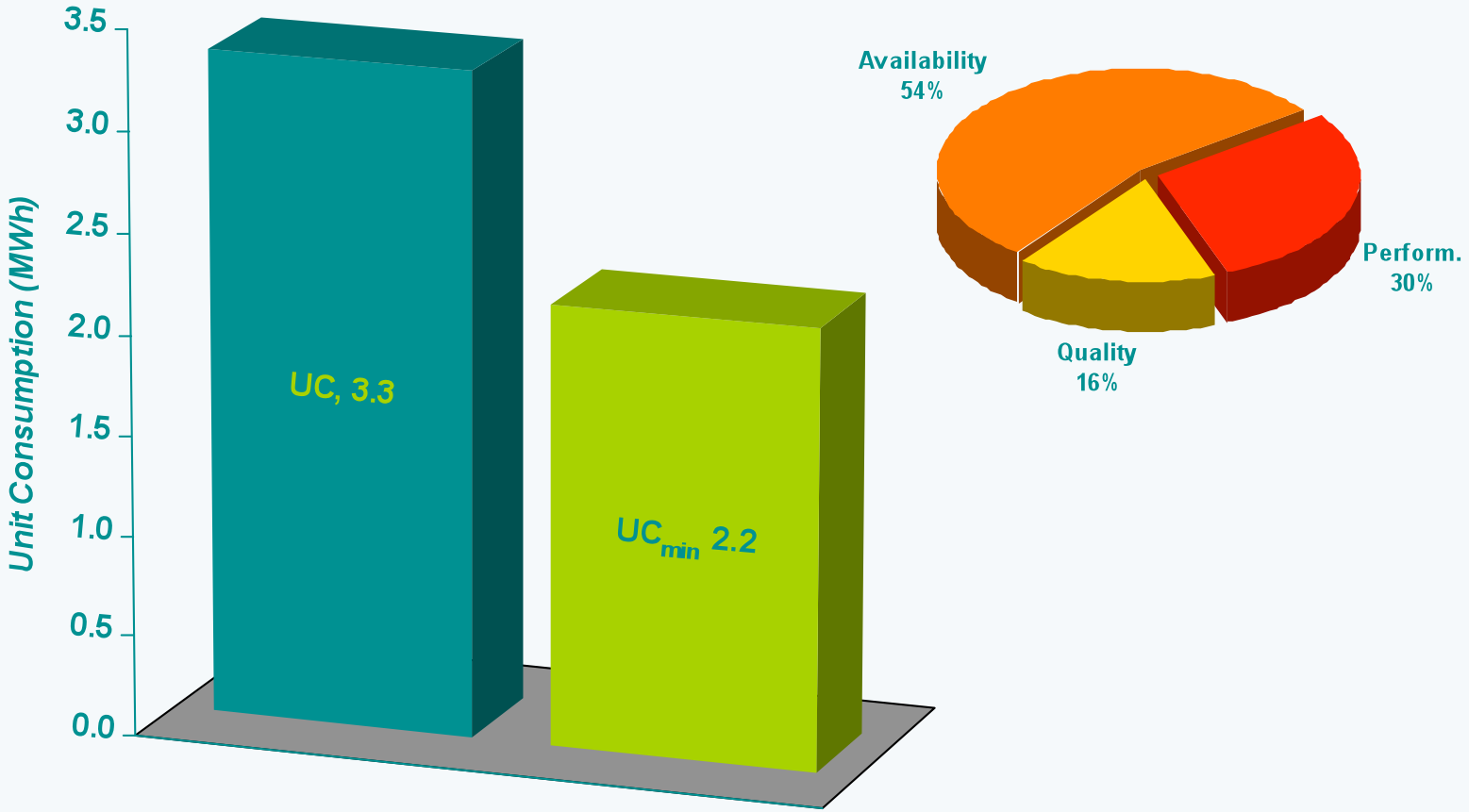
Example: Unit consumption & OEE

- **Week 44:** Production Output = 482 units *(UC = EC/PO)*



Example: Unit consumption & OEE

- **Week 44:** Production Output = 482 units *(UC = EC/PO)*
- OEE = 53.6% *($UC_{min} = EC_{th}/PO_{th}$)*
- Quality = 91%, Availability = 70%, Performance = 84%



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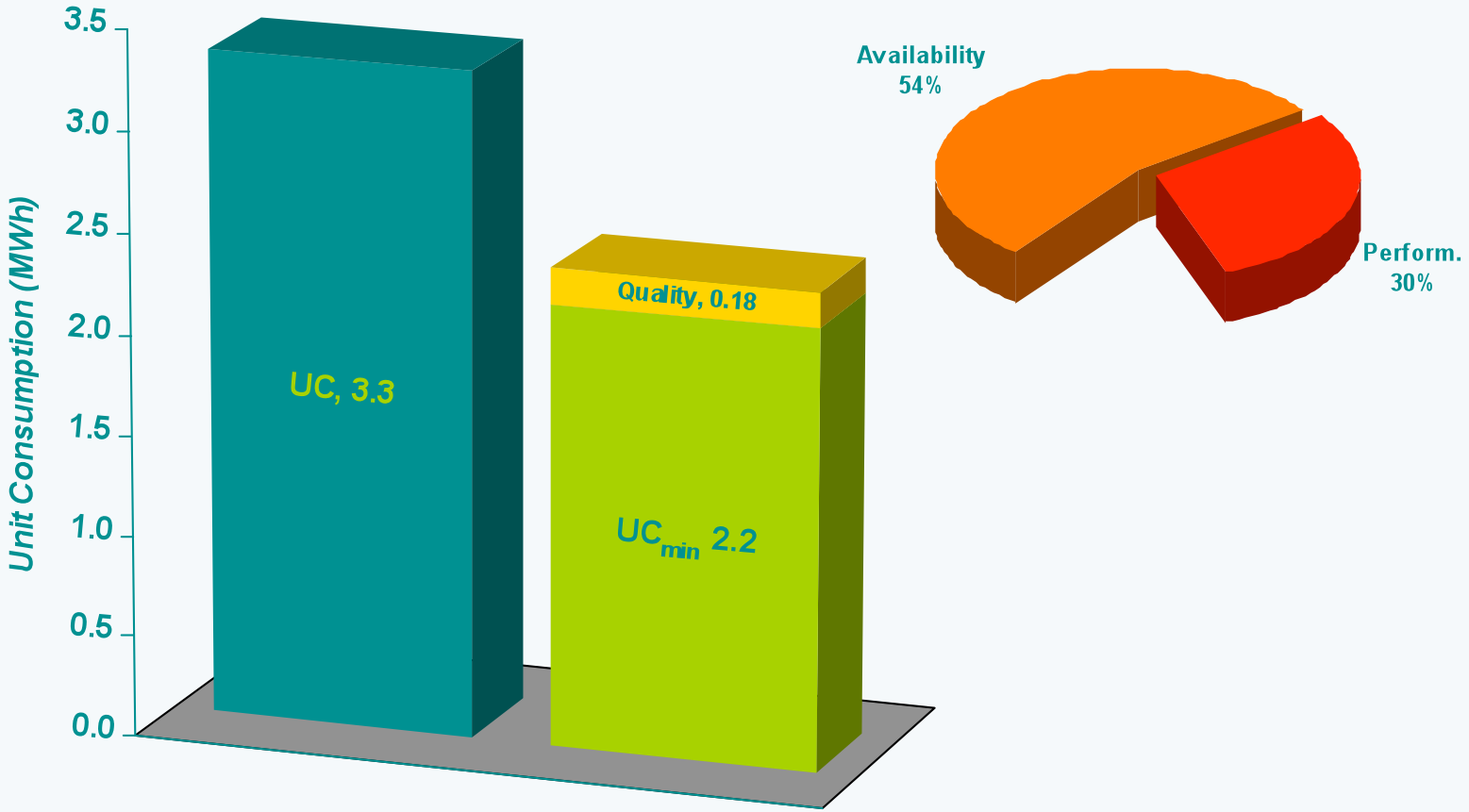

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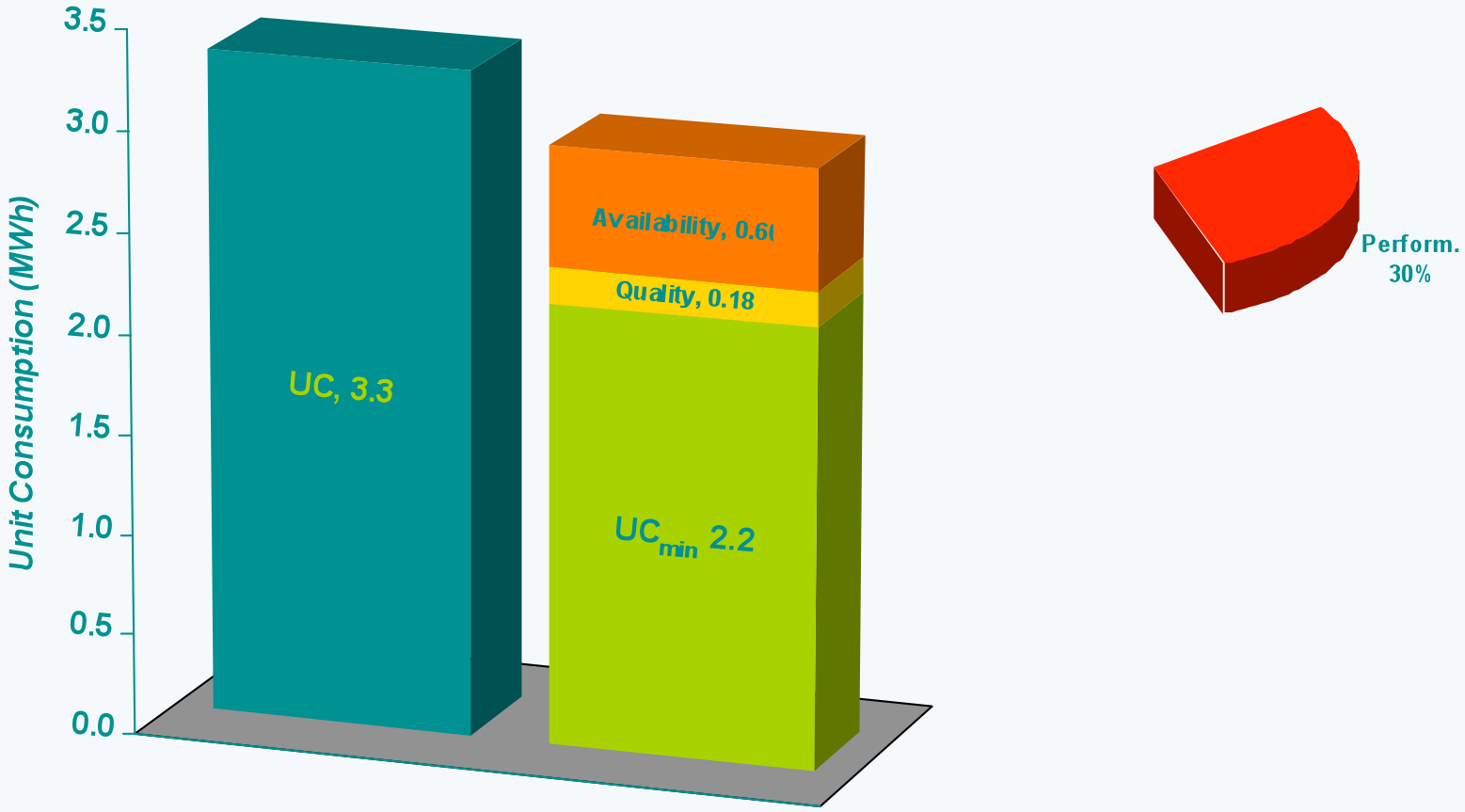

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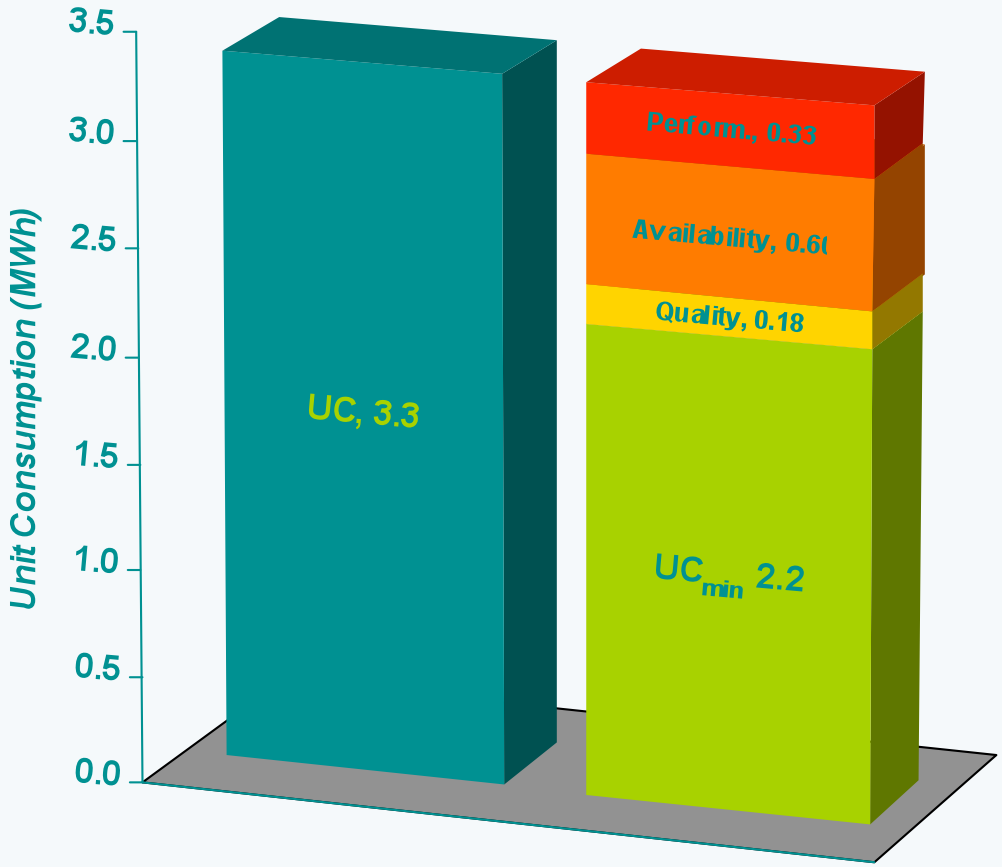
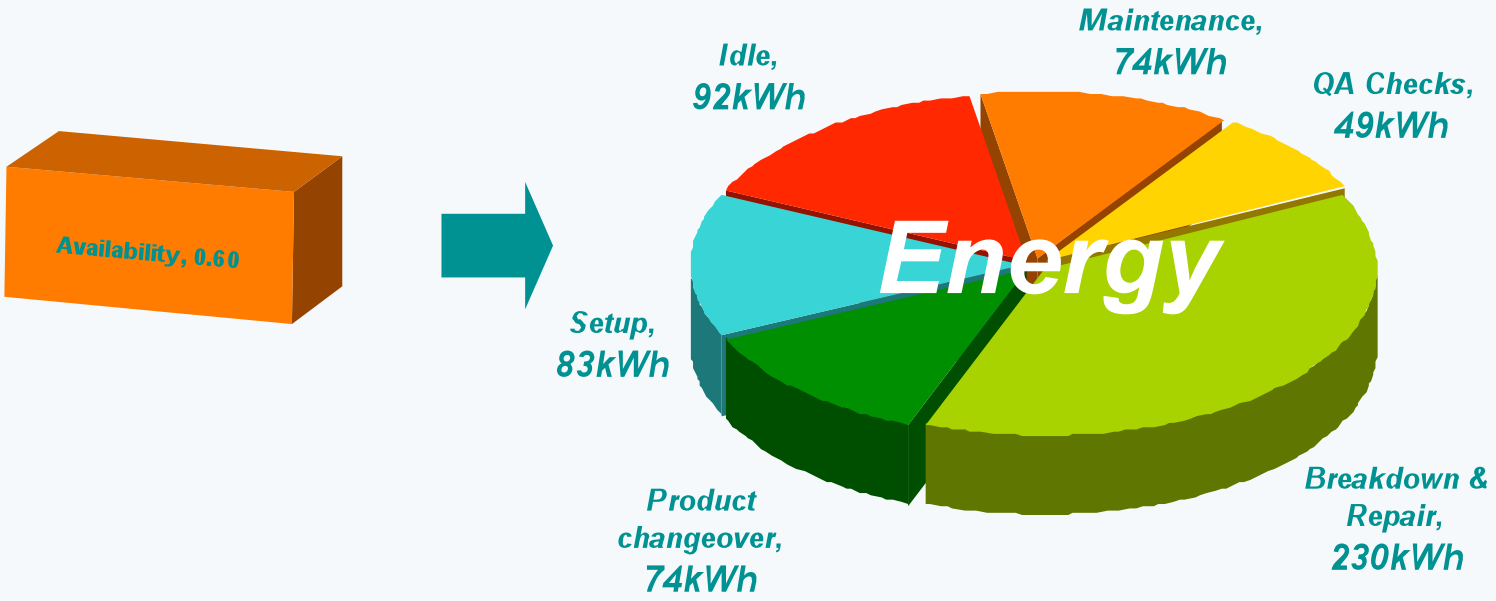


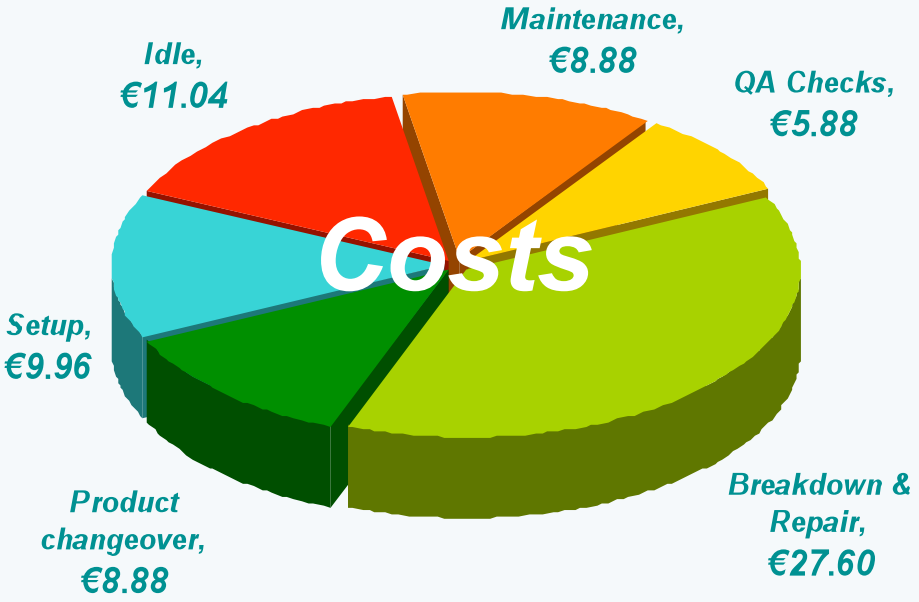
Example: Unit consumption & OEE

- Each OEE component can be further broken down and energy quantities attributed to causes of failure
- Each cause has an associated energy waste figure



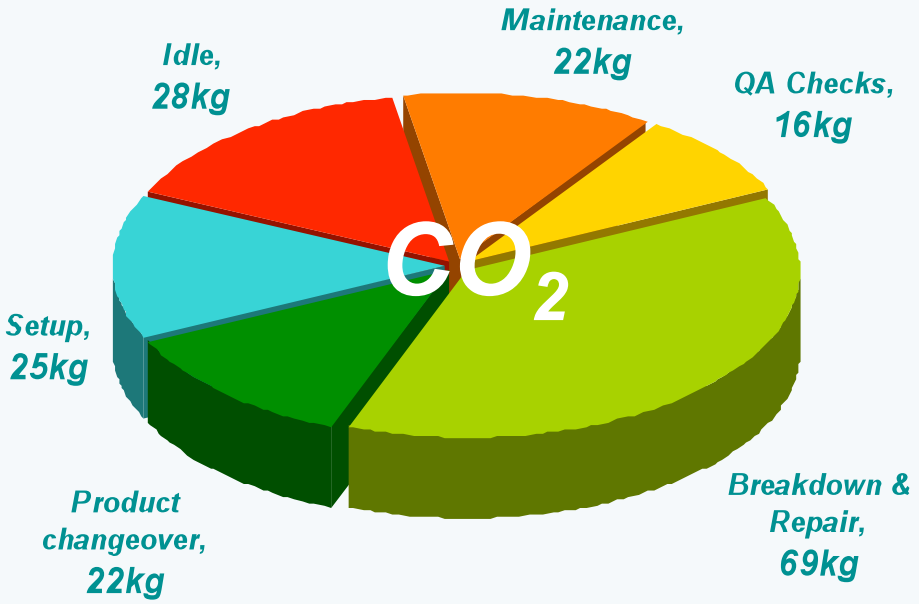
Example: Unit consumption & OEE

- Using an average unit energy cost a value of wasted energy can be calculated for each cause
- e.g. *Breakdown & Repair was responsible for €27.60 of wasted energy per unit produced in Week 44*



Example: Unit consumption & OEE

- Similarly, average CO_2 emissions values can be applied to get emissions attributed to each cause
- e.g. *Stoppages due to QA Checks accounted for 16kg CO_2 emissions per unit produced in Week 44*



From OEE to OFE

- OEE: a measure of efficiency of a machine or line
- OFE: (Overall Factory Effectiveness) efficiency of complete manufacturing plant
- OFE could be used to assign energy losses to inefficiencies in overall plant processes
- OFE metric still in early stage of development (manufacture of semi-conductors)

Additional points

- Methodology could be used for specific fuel types or energy-consuming utilities, e.g. steam
- Model measures efficiency of plant *"as is"*; Changes to plant will lead to changed energy model
- Compare UC_{min} before and after plant modifications or device-oriented EE measures to quantify savings
- **Need real plant data to validate the model !**

In conclusion…

- Proposed model complements existing plant energy models
- EE gains through productivity can be pursued in tandem with device-oriented EE measures
- Model can quantify EE improvements to be gained by increased productivity
- Model can assign energy waste to specific causes
- Costs of wasted energy can be assigned to individual cost centres – not overheads

Thank You

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