Project Deliverable

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Instrument:	Thematic Priority
COLLABORATIVE PROJECT	NMP

Title
D1.4 Visualization concept for multi-dimensional resource efficiency indicators

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PP	Restricted to other programme participants (including the Commission)	**PU**
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CO	Confidential, only for members of the consortium (including the Commission)	

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604068.

Abstract :

The aim of MORE Task 1.4 was to develop suitable visualization techniques for the resource efficiency indicators that can be easily understood by plant operators and plant managers. The resource efficiency of production processes in the chemical industry can rarely be characterized by one indicator alone. Thus, resource efficiency arises to a multi-dimensional entity that calls for efficient visualization methods to show the overall state of the system, dependencies between individual aspects of resource efficiency, and transients in the systems performance. This deliverable specifies visualization techniques in due consideration of the dimension and the intended purpose of the application. The enclosed decision table can be used to guide the selection of a visualization concept for many decision support and monitoring applications from the chemical industry. In conclusion a dashboard for one case study is presented.

Authors (organisations) : TUDO, INEOS

Keywords :

Real-time resource efficiency indicators, REI, visualization, monitoring

Disclaimer

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Revision History

The following table describes the main changes done in the document since it was created.

Revision	Date	Description	Author (Organisation)
V1	20.01.2015	Creation	M. Kalliski, TUDO
V2	27.01.2015	Approval by Prof. Engell	M. Kalliski, TUDO
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1. Introduction

In the first three deliverables of WP1 guidelines for the definition of real-time resource efficiency indicators were developed with the goal that the indicators are capable of capturing the technical performance of continuous and batch processes with respect to the efficiency of energy and material use. The resource efficiency of production processes in the chemical industry can rarely be characterized by one indicator alone. In cases where it is impossible or not sensible to aggregate indicators into one universal indicator, resource efficiency becomes a multi-dimensional entity. Individual aspects or dimensions of the resource efficiency might be coupled or entirely unrelated and information about this relationship can be exploited for decision support to improve operations. Additionally, the indicators are used to monitor the current state of the system as well as a retrospective reporting tool to identify drifts and potential problems in the future.

This deliverable aims at developing visualization techniques to present the necessary set of REI in an easily comprehensible way to the operational personnel, especially in the case of multi-dimensionality. First REI representations are listed and discussed. Then, a decision matrix is presented that gives a recommendation for a visualization method based on the requirements posed by the user. Finally, a dashboard concept for the INEOS case study is presented that serves as vantage point for the further development.

2. Visualization methods

Visualization techniques are used to present data to the user in a somewhat abstracted representation that is intended to ease the interpretation process by giving meaning to data and supporting an efficient perception. The first step towards a good representation of the resource efficiency of a chemical production plant is the definition and selection of key indicators that accurately represent the true plant performance. This was previously accomplished in the form of resource efficiency indicators (REI) within the deliverables D1.2 for continuously operated processes and D1.3 for batch processing plants. The next step is to find the visualization techniques that represent the REI best on a human-machine-interface.

In general a well-designed dashboard conveys information that is [1]:

- Exceptionally well organized

  The representation of complex systems requires multiple REI and supporting information, thus multiple plots and graphs are needed. Grouping in rows, columns fields increase readability and reduce the time required to find the needed information. Texts written in the languages of the participating project partners are read from left to right and up to down. Taking advantage of this habit the most important information should be displayed in the top left area and the least important on the lower right (cf. Figure 1).

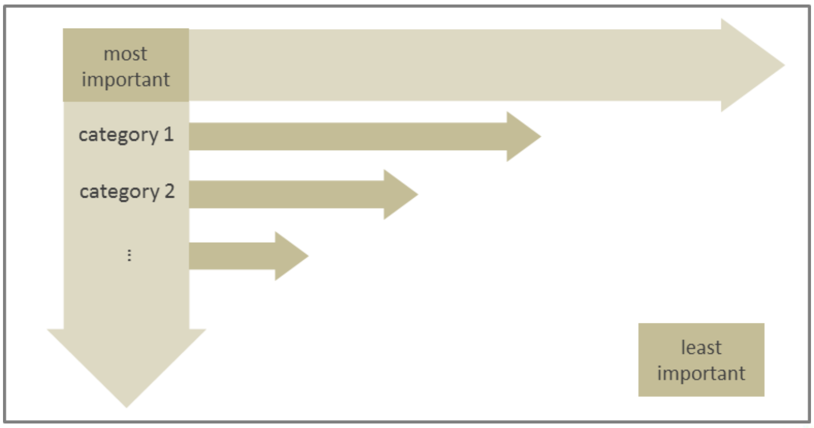

Figure 1: Structure of well-organized dashboard configuration.

- Condensed, primarily in the form of summaries and exceptions

  Information in the form of hundreds of data points is not helpful in the interpretation process. The defined REI are in fact summaries over meaningful time scales and subsystems making it possible to see the whole picture. Data plots show plant behavior in the bounds of normal operations should be displayed unobtrusive (light colors with low intensity), in order not to draw the attention away from information that is more important. More intense colors and forms of representations should dynamically occur in the case of exceptions (a situation that requires the operator evaluation or input).

- Specific to and customized for the audience and objectives

  The kind of information presented to the recipient should be based on what is needed to execute the task at hand. Insight in what this information is can efficiently be gained by observing the operational procedure in the current set-up and questioning why and on what basis a decision was made.

- Displayed using concise and often small media that communicate the data and its massages in the clearest and most direct way possible

  The content and density of information in a visualization element should be limited to a minimum which still serves the intended purpose. This includes aspects like background coloring, background pictures and unnecessary grids and borders. These rules were introduced as the concept of “data-ink ratio” by Edward R. Tufte [2], stipulating the reduction of non-data ink.

Based on these requirements to dashboard representations S. Few [1] identified 13 common violations of these rules that should be avoided in the design of effective visualization solutions.

- Exceeding the boundaries of a single screen
- Supplying inadequate context for the data
- Displaying excessive detail or precision
- Choosing a deficient measure
- Choosing inappropriate display media
- Introducing meaningless variety
- Using poorly designed display media
- Encoding quantitative data inaccurately
- Arranging the data poorly
- Highlighting important data ineffectively or not at all
- Cluttering the display with useless decoration
- Misusing or overusing color
- Designing an unattractive visual display

Below visualization concepts are discussed that were identified in progress of task 1.4, analyzing which formats are most useful for the visualization goals: the identification of trends (dynamic behavior), monitoring compliance with production targets, obtaining an overview of the process or showing quantitative and qualitative aspects of resource efficiency.

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2.1. Indicators included in plant structure

REI can be defined for smaller subsystems of the plant, by introducing bar scales to the flow diagram of the plant set-up, summarizing the resource efficiency, which helps to keep a good overview of the process efficiency for the operational staff (c.f. Figure 2).

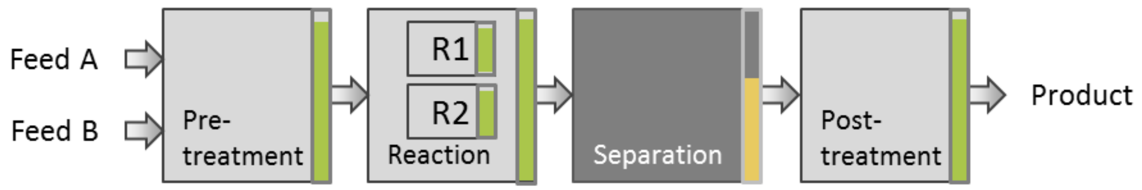

Figure 2: Overall efficiency indicators in plant structure diagram.

If the indicator value of a subsystem drops below a minimal target value the section is highlighted by a darker shade of gray and the bar will change the color from green to yellow and for very low values to blue in order to motivate the operational staff to intervene.

2.2. Sunburst diagrams

In chemical processes raw materials and energy are consumed whilst producing the desired product as well as material- and energy-waste streams. Sunburst diagrams (c.f. Figure 3) are useful to visualize the distribution of energy and materials from plant level to unit level.

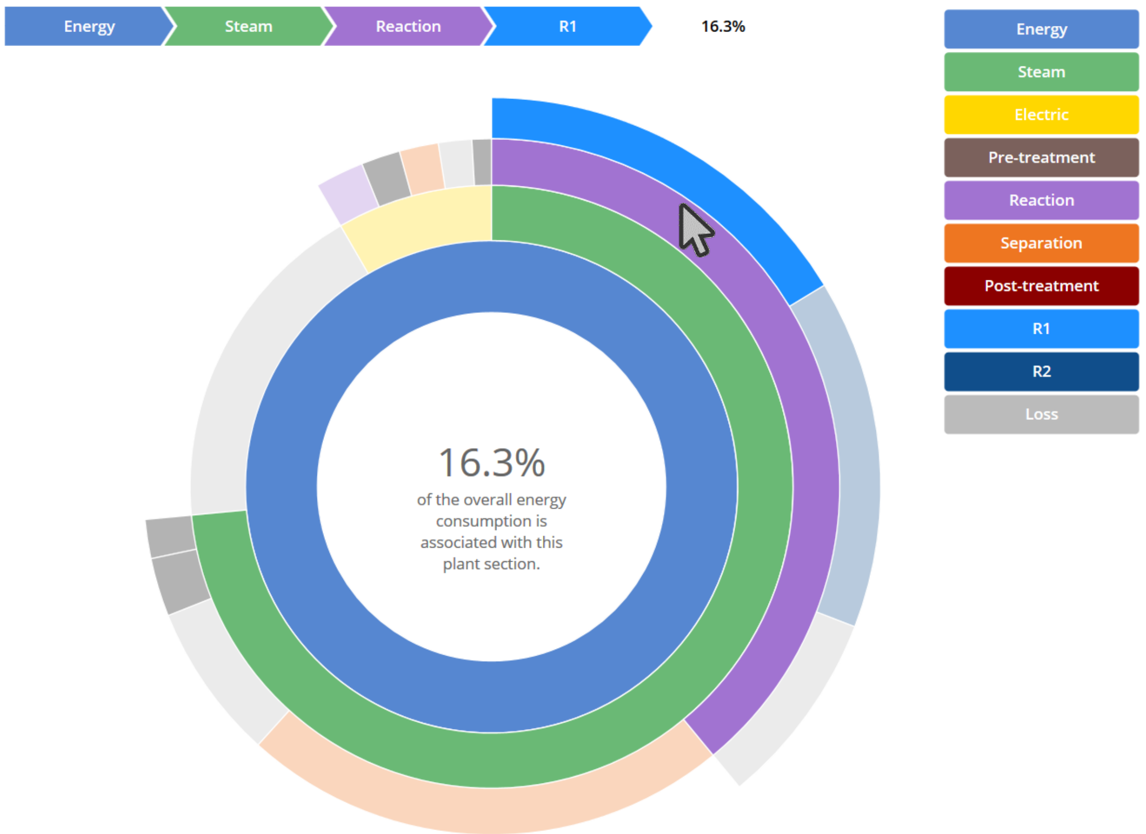

Figure 3: Sunburst diagram for the energy consumption by plant section.

The visualization based on the circular design and multiple layers representing the plant hierarchy allows the user to compare shares on the same levels as well as on different levels. Main consumers are identified effortlessly and may point out where to check for optimization potential first. Upon user input the category

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of interest and the trail from the highest level (center of the circle) is highlighted, supported by the display of the numerical value shown in the middle of the diagram. Additionally, the trail of categories is shown on the top left corner, which minimizes the need to consult the legend on the right of the diagram. This visualization technique is most suited to give an overview of the energy consumption on an energy or site management level but is too coarse to derive operational actions from.

2.3. Sankey diagrams

Sankey diagrams abstract a given plant structure and visualize the pathway of material and energy through the system. The upper half of the Sankey diagram in Figure 4 shows two raw materials being fed to a reactor yielding a mixture of the product with impurities that is fed into the consecutive separation stage where the mixture is split into pure product and waste material.

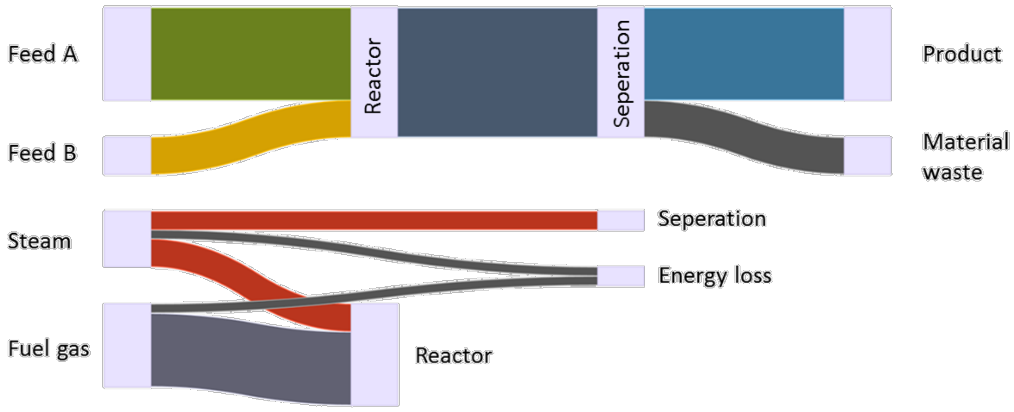

Figure 4: Sankey diagram for materials (top) and energy (bottom).

The mirrored plant structure in the lower half depicts the flow of energy into the reaction and separation step, as well as the associated losses. The Sankey diagram fulfills the same purpose as the sunburst diagram but is suited better for complex systems and pathways, because of the incorporation of the systems structure.

Upon user input the selected streams are highlighted by increasing the transparency of the rest of the diagram, while displaying the flowrate and the theoretical minimum necessary to produce the same amount of product (c.f. Figure 5). This visualization technique is suitable to track mass and energy flows through the plant but may be too complex for the operational personnel.

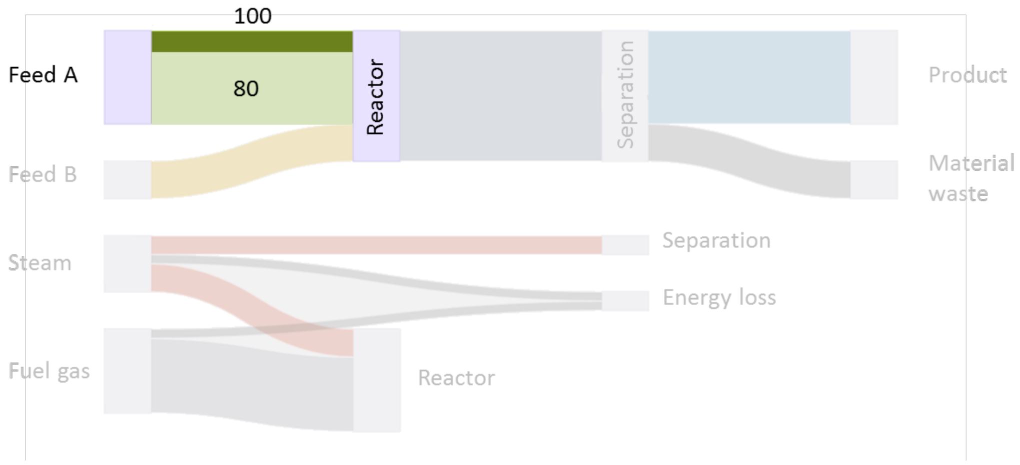

Figure 5: Sankey diagram with highlighted raw material feed A with a measured flowrate of 100 and a theoretical minimum of 80 to produce the same amount of product.

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2.4. Radar plots

Figure 6 shows radar plots for five indicators that were referenced against a theoretical or historical optimum, thus they can adopt values between 0 (poor efficiency) and 1 (perfect efficiency). The light brown area depicts a performance below an individual target. As long as all indicators are above the target, the system is considered to be well operated. The target threshold differs from case to case and needs to be carefully defined by the plant management specifying the dashboard. The plot on the left hand side shows a static version that is useful to obtain a fast overview about the process at one glance. On the right hand side of Figure 6 a dynamic radar plot indicates the current situation with a black line and previous configurations in gray, where lower intensities stand for values further in the past. This is especially useful for batch processes.

This visualization concept is very well suited for the verification of compliance with targets and can be broadly used to show qualitative tendencies. The minimal number of indicators required to produce a radar plot is three, being theoretically unbound for the maximal number of REI to be shown. Practically the interpretation of the plot becomes ambiguous for significantly more than five REI.

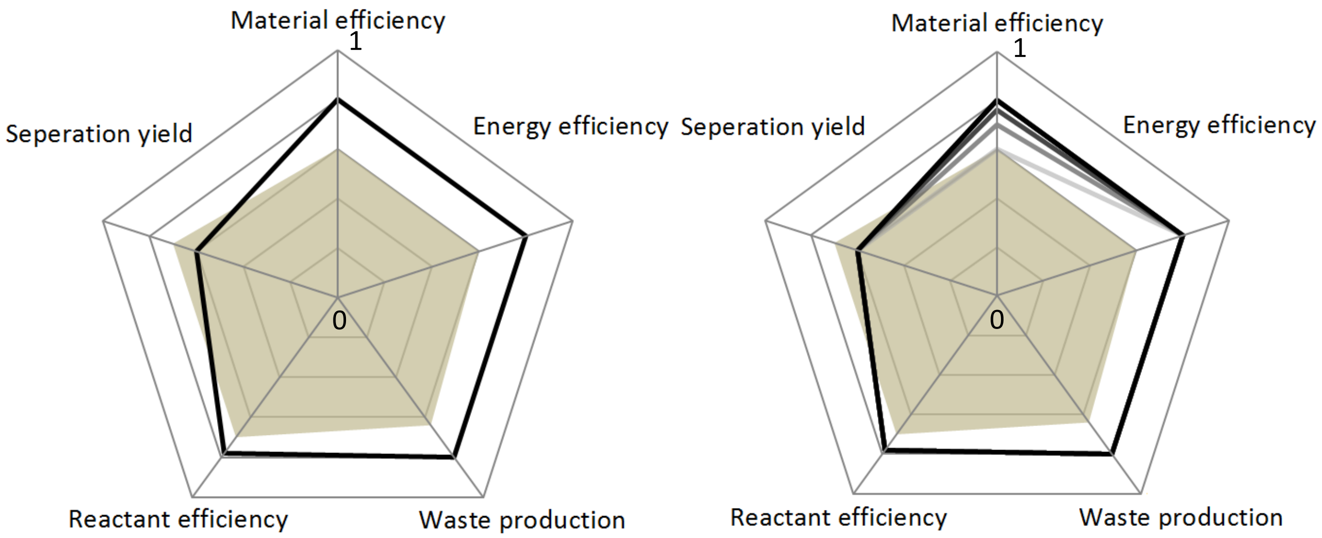

Figure 6: Static (left) and dynamic (right) spider web plot for selected indicators.

2.5. Bullet chart

Figure 7 shows a bullet chart that conveys more detailed information than the dynamic radar plot, using parallel scales [3]. Similar to the indicators used in the radar plot the REI should be defined with respect to a theoretical optimum or best achieved value (100%). The white interval of the scale indicates the interval above the target value, the gray interval below the target value respectively. The lower bound of the scale should be chosen as 0% to achieve a consistent and comprehensible visualization. In case the desired domain of operation is very close to the optimum for all indicators, it is useful to choose a higher value as lower bound for the scale. Nevertheless, the limits of all scales arranged next to each other must use the same limits to ensure comparability among the indicators. Triangles are used to mark the current value and are complemented with the numerical value on the opposite and an arrow designating the direction of movement based on the immediate past. The colored rectangle is the variability bar and shows the range of values that was exhibited during a time period indicated on the lower right. In case the an indicator leaves the white interval an exception occurs that is emphasized by a change in color of the variance interval/numerical value and the appearance of a caution sign above the scale.

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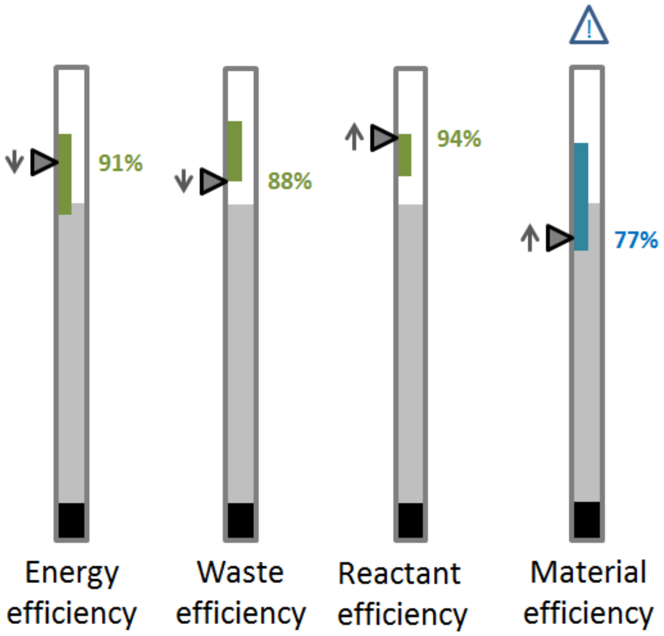

Figure 7: Bullet chart representation with current value, direction of movement, historical variability and relation to reference.

The number of Indicators that can be perceived by a user is higher in comparison to the radar plots because of the aligned orientation, which reduces the cognitive effort necessary to interpret the data (the rule of restricting the visualization the necessary information still applies). The history of the indicator is stored implicitly in the size of the variability bar, the current position relative to the variability bar and the arrow indicating the direction of movement. If the plant operates stable within the desired efficiency range the variability bar is small and lies entirely in the white area (TRE). An upset plant manifests in large variability bars that may or may not reach into the sub-target range (TME). A triangle position at the border of the variability bar in combination with an arrow pointing further away from the variability bar indicates a transient trend away from the former average (TWP) which can be an early indicator for the operator to intervene and take corrective measures. Finally the color change and appearing warning signal drag the user's attention to the state.

Bullet charts do not necessarily have to be oriented from bottom to top, but could also be displayed top to bottom (in a minimization task) or with an orientation from left to right, depending on the available dashboard space and the context they are used in.

2.6. Stacked bars and stacked area plots

Stacked bars and stacked area plots are used to represent data that is meaningful when aggregated, e.g. multiple types of consumed energy per product that adds up to the total energy consumption per product. The distinction between stacked area and stacked bar plots is made because the same data is perceived differently by the human eye (c.f. Figure 8 and Figure 9).

In area plots the integrals of the contributing factors are naturally recognized and compared against each other. Furthermore it is easier to compare more distant states in time by simply imagining a horizontal line in the diagram, i.e. the steam consumption in October 2012 rises above the initial value in the end of 2011 after a drop in April 2012. It also appears that the electricity and steam consumption are somewhat exchangeable due to the fact that the overall energy consumption changes only little.

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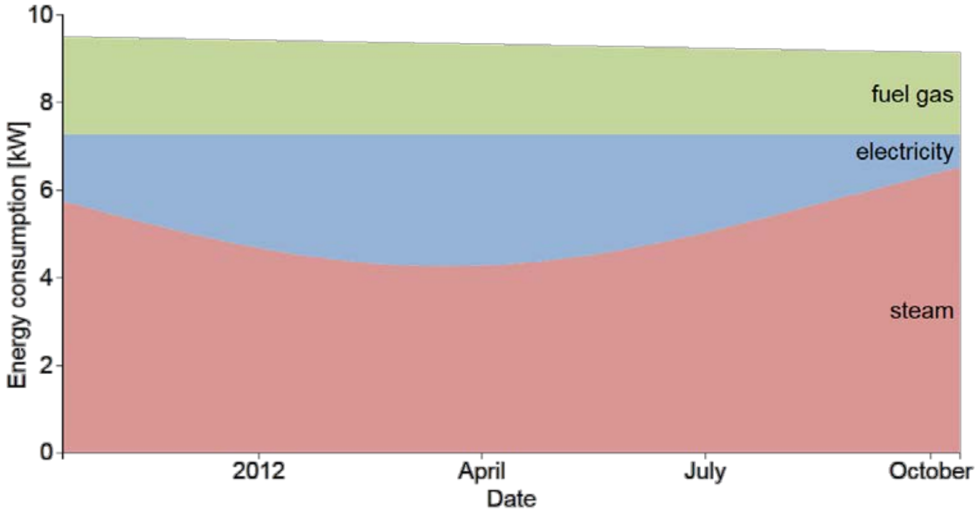

Figure 8: Stacked area plot.

Individual bars on the other hand are perceived as units at each instance which naturally implies the use for batch processes. Additionally, the use for continuous processes makes also sense if the energy mix changes discontinuously from aggregation interval to aggregation interval. Due to perceptual effects it is easier to compare bars in close time proximity because they are associated with specific points in time, while not losing the information about tendencies in the overall energy consumption (c.f. Figure 9).

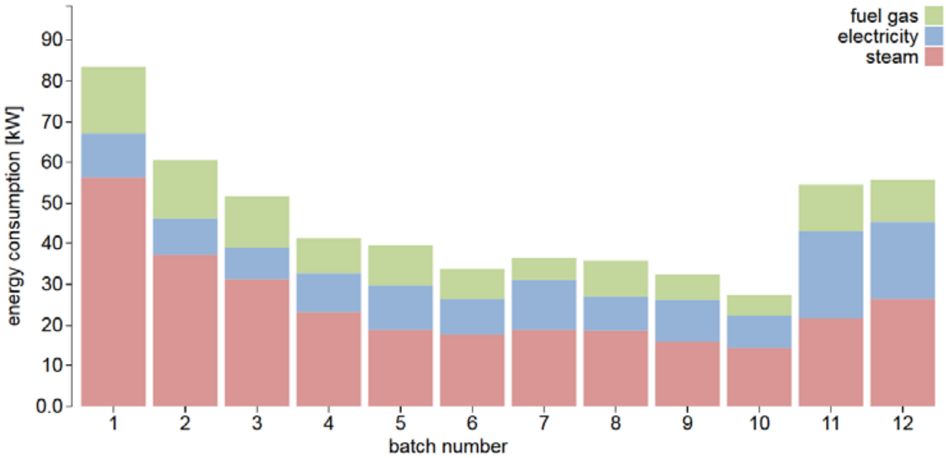

Figure 9: Stacked bar chart for batch applications.

2.7. Trajectory plots and difference charts

Simple line plots are a common tool to visualize data and help to identify trends in large time dependent data sets. However, the utilization of line plots in the decision making process of operational staff in chemical production facilities without any additional interpretation aid requires the user to consider other information that could easily be supplied alongside the plot. By including additional information, e.g. equipment limits, process knowledge and experience, unnecessary cognitive effort is avoided and the time to the comprehension is reduced.

The form of the interpretation support depends on the intended purpose of the graph. If only the approximate trend and the current value are important, sparklines can be used with a minimal amount of dashboard space and distracting non-data pixels (c.f. Figure 10) [4]. On the right hand side of the figure the current numerical value and variable names are shown. Even without any scales transients in the variable

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are apparent to the human eye. Additionally, upper and lower limits (grey bars) might be introduced to reveal violations of target levels.

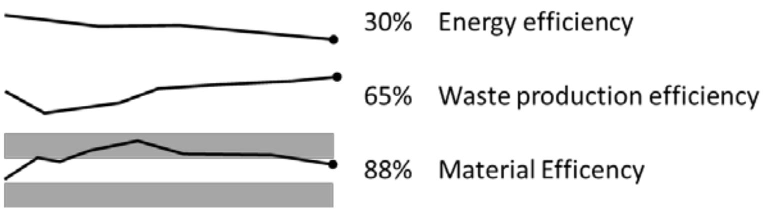

Figure 10: Sparklines for three REI in different set-ups.

Another application is the monitoring of dynamic systems like the reaction phase in a batch process (c.f. Figure 11). If first principal or data based models are available, it is possible to obtain trajectories that yield the desired product quality without violating any constraints imposed by technical capability, safety concerns and production objectives. Staying in the trust region framed by the dashed lines ensures a product mixture that is in specification. A deviation from the optimal trajectory (solid gray line) gives the operational staff time to take corrective measures to avoid violation of the trust limits. Only if the reaction trajectory leaves the trusted region an additional, sometimes time consuming, quality analysis is needed to confirm if the product material is in-spec, thus reducing the analytical effort.

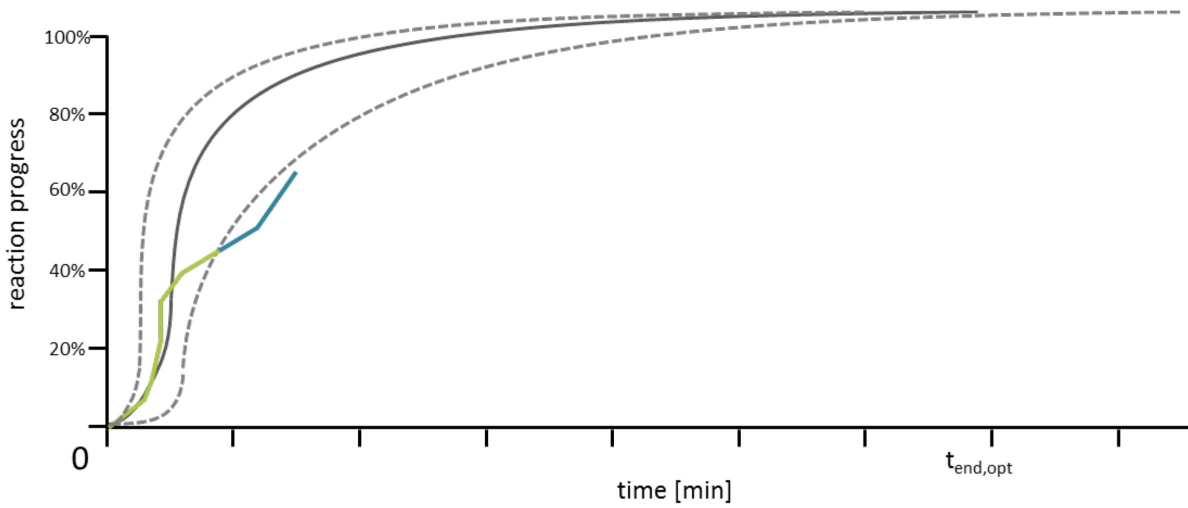

Figure 11: Real-time trajectory plot of the reaction progress of a batch reaction phase. Optimal trajectory (solid gray line), normal operation range (dashed gray line) and the current trajectory (green/ blue line).

Difference charts (c.f. Figure 12) are another expansion of line plots very well suited to depict REI like the product specific steam consumption in reference to a target value. By color-coding the areas enclosed between the reference and the measured data saved (green) and lost (blue) contributions to the steam consumption are highlighted. With this visual aid it is possible to compare the resulting areas and evaluate the operational performance. If the boundary conditions are changing, due to a different production capacity or external influences, the reference changes as seen in Figure 12.

If there is reason to expect a large number changes in the reference, the ordinate should be changed from absolute values to a positive and negative deviation in percentages from the reference. Thus, the reference appears as a straight line on the abscissa resulting in improved perceivableness.

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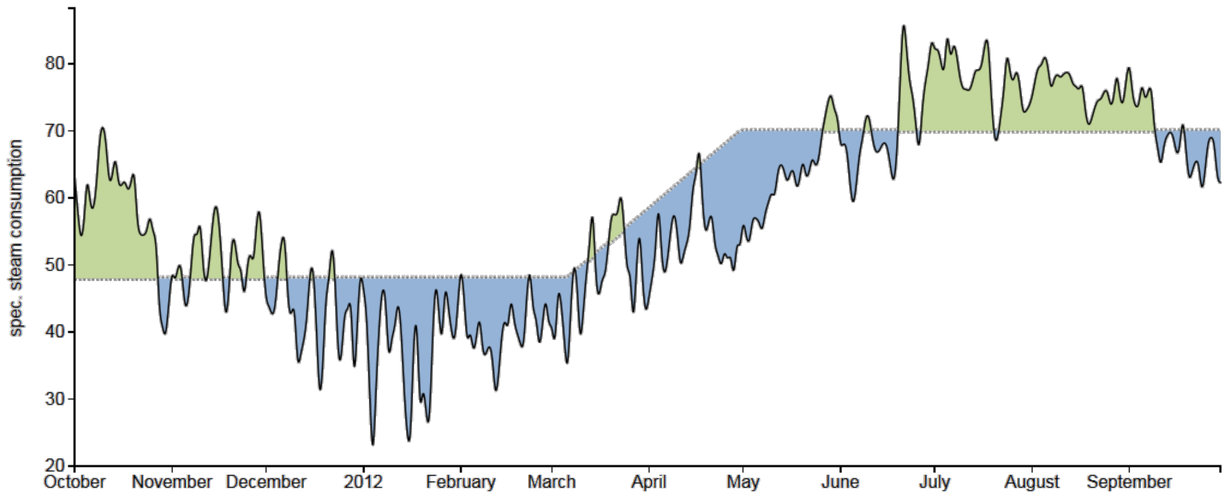

Figure 12: Difference chart to reference, blue areas are losses compared to reference, green areas are gained to reference.

2.8. Aggregated tiles

Data representation with aggregated tiles (c.f. Figure 13) uses color-coding in order to show a certain property of a data set. In this instance averaged REI over intervals of 30 minutes are depicted as square tiles which can be evaluated by color according to the scale below. For an inefficient state of the indicator blue and brown shades are used, in contrast efficient operating points are represented with colors ranging from orange over yellow to green. Additionally, the arrows on the right denote the current state by color and the direction of movement by the orientation of the arrow.

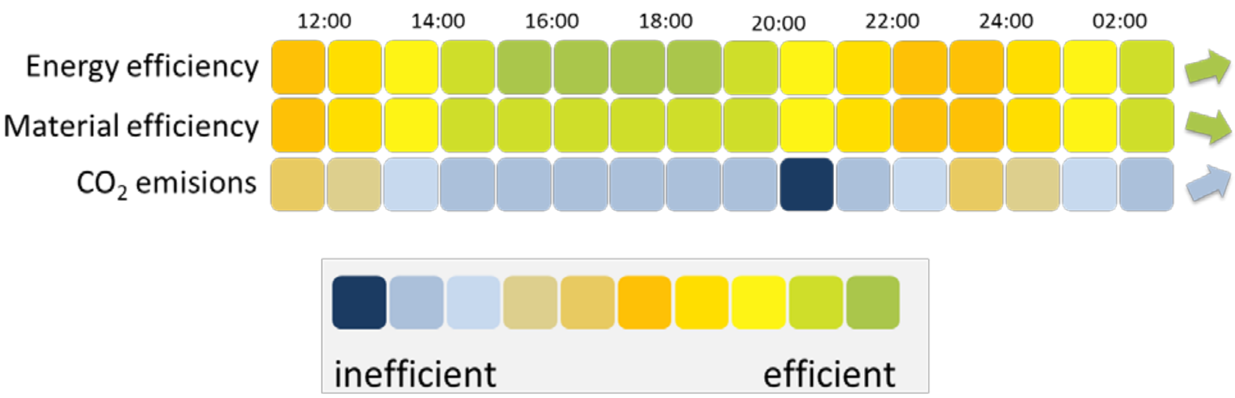

Figure 13: Aggregated tile plot with color according to the efficiency.

This visualization method does not facilitate quantitative information, but allows for the comparison of indicators that cannot be directly translated into each other because of different units or due to the fact that they monitor entirely other effects. It is even possible to compare batch process data with data of a continuous process. The user intuitively recognizes trends in the respective row of each indicator and can furthermore identify pairs or groups of indicators that either exhibit opposite or consistent correlation.

The aggregation interval needs to be chosen carefully for continuous data, in order to be meaningful. In case the data origin is a batch process each tile represents a batch or campaigns.

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3. Selection of visualization elements for efficient concepts

In the previous chapter eleven methods of data visualization were summarized and analyzed for which kind of data and visualization goal they are suited best. A comprehensive overview is given in Table 1. If the considered method fully meets the one of the requirements listed on the left, then this is indicated by a "+" sign in the corresponding field of the matrix. A "o" sign is used if the criterion is partially met and the field is left blank if the form of presentation is not suitable for the requirement. If the selection criteria for a planned visualization task are defined Table 1 can help to select appropriate methods to create the most efficient dashboard solution possible.

Table 1: Comprehensive overview for the visualization methods introduced in this deliverable.

	Plant structure diagram	Sunburst diagram	Sankey diagram	Radar plots	Aggregated tiles	Bullet charts	Stacked bars	Stacked area plots	Sparklines	Trajectory plot w. trust region	Difference charts
Plant overview	+	+	+	+	o						
Qualitative	o	+	+	+	+				+		+
Quantitative		o	+			+	+	+		+	o
Batch data			+	+	+	+	+			+	
Continuous process data			+		o	+	o	+	+	o	+
Trends				o	o	o	+	+	+	+	+
Many indicators (>5)		o	o		+	+			+		
Indicator history				o	o	o	+	+	o		o
Fluctuating data						+	+		+		+
Absolute	+	+	+	+	+	+	+	+		+	+
Relative	+	+		+	+	+	+	+		+	+

The monitoring of resource efficiency in chemical production plants is a complex multidimensional task that requires highly efficient human-machine-interfaces to convey information of the process state to the operators. Since the amount of information that can be apprehended is limited, the focus of the operator needs to be guided to the relevant information at any time. An effective visualization uses the simplest and most suited method to relay information about an aspect of the data.

In most cases it is not possible to display all aspects equally excellent in just one diagram, thus it is beneficial to use methods alongside each other that highlight different aspects, i.e. a plant structure diagram with bar indicators for the total efficiency of the section can be used to show the overall state, along with stacked bar charts that further break sown the contributing factors of the overall efficiency. With a smart selection of visualization techniques that built on one another and highlighting important data, exceptionally efficient HMI can be created.

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4. Application to the INEOS case study

The core goal within the project MORE is to create a decision support system for staff members to improve the day-to-day operation of chemical production plants. Based upon carefully defined REI what-if analysis and decision support tools are currently being developed in MORE. These systems require powerful visualization solutions, specifically designed to convey REI information. Below, dashboard prototypes for monitoring the case study supplied by INEOS is presented, which will later serve as blue print for the remaining case studies and other applications.

The INEOS case study comprises an acrylonitrile process with two parallel production lines and an upstream compressor facility providing the necessary pressurized air. Acrylonitrile is a bulk chemical and is produced continuously, which poses different challenges. The expressed requirements from the operational staff included a smart representation of the multi-layer hierarchy, a high level of flexibility in the visualization, and a comprehensive dashboard design.

Figure 17 shows the dashboard for the acrylonitrile (ACN) plant with the process flow sheet in the top left area, combining the resource efficiency overview (indicator bars) and the navigation through the systems hierarchy (by double-click). A single left mouse-click will select the plant section as a basis for the indicator calculation. The control buttons to enable and disable the visualization of the indicators are located directly below the process flow diagram. Each of the buttons triggers the display of the corresponding row of tiles representing the history of the indicator aggregated for 30 minute intervals. At the end of the row an arrow shows the current direction of movement by its orientation and efficiency by its color. After choosing a diagram type the data is plotted into the graph for further inspection.

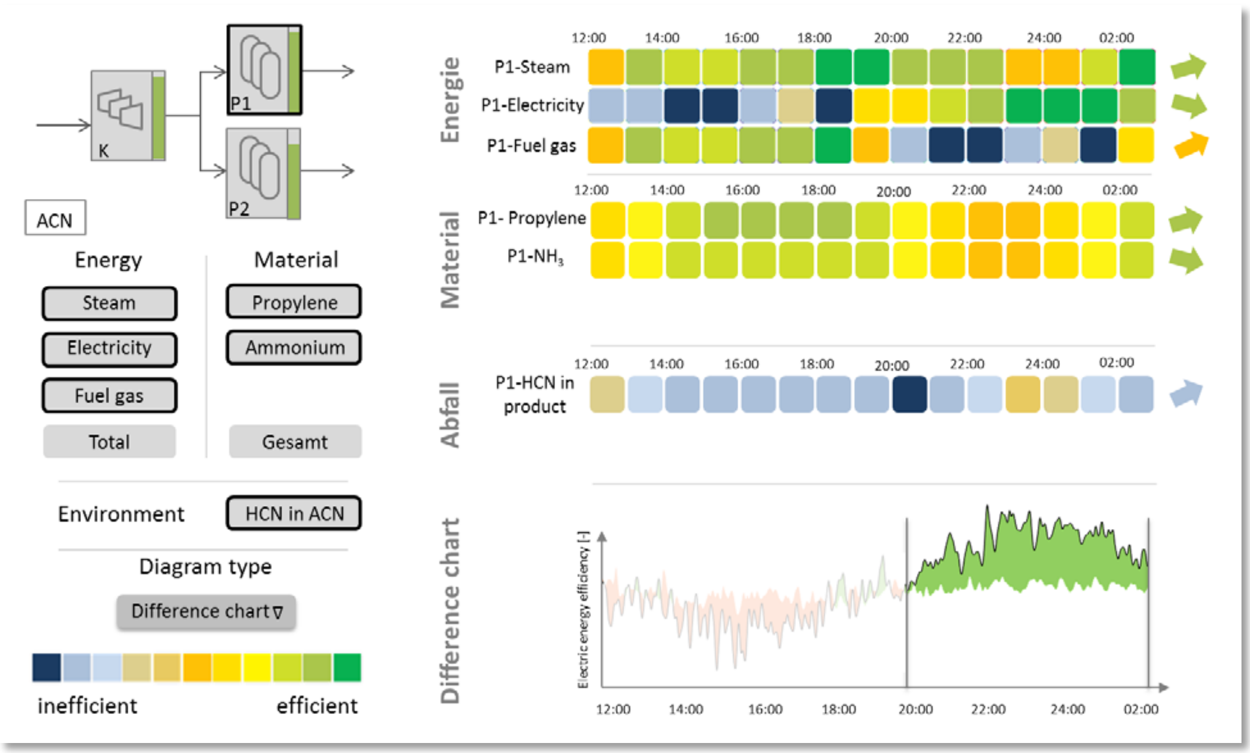

Figure 14: Dashboard for INEOS continuous case study.

The plant section P1 is selected in order to analyze the associated resource efficiency. For the past 14 hours the plant was operated relatively efficient, only the indicator to measure the traces of hydrocyanic acid (HCN) in the product is indicating a bad performance. If desired, the user can click on one of the aggregated tile rows to get additional information on this indicator in the form of an

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additional graph below. The method of visualization used, depends on the users selection in the drop down menu. As an example the difference chart for the amount of electricity consumed by plant section P1 is shown. The areas in the difference charts are the lost (red) and saved (green) amounts of electric energy compared to the baseline which is presented to the user.

5. Summary

The deliverable D1.4 summarized the findings of task 1.4 and presented concepts on how to find the most efficient visualization methods to represent the resource efficiency of chemical production plants to operational staff. In section 2 existing techniques for data visualization with relevance for the MORE project were presented and used to create innovative concepts, which are specially designed to meet the requirements of process monitoring based on REI. All types of visualization were analyzed to define selection criteria that can be used to systematically find the best solution for any given application. Table 1 provides a clear overview, matching requirements with the visualization techniques suited best for the task. Finally, a dashboard solution for one industrial case study was presented that will serve as a basis for the what-if and decision support tools.

In the next project phase operational staff needs to test the prototype solutions and give feedback for further developments. Ultimately, the dashboards need to be extended by optimization routines in order to reach the ambitious goal set for the MORE project.

6. References

[1] S.Few, Information Dashboard Design - The Effective Visual Communication of Data, C. Wheeler, Ed., Sebastopol: O'Reilly Media, 2006.

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