

Module 10: Data-Driven Decision Making and Strategic Planning for I-US

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SYMSITES

Module Overview

This last module introduces the digital tools and data-driven approaches that support monitoring, optimization, and decision-making in I-US. The module explores how industries and SMEs can integrate IoT sensors, interoperable data systems, and visualization platforms to monitor resource exchanges and operational performance. It also examines how real-time data processing, analytics, and AI-based tools can transform raw process data into actionable insights for predictive planning and adaptive management.

- [Chapter 10.1: Data visualization and system integration](#)
- [Chapter 10.2: Incorporating Real-Time Data Processing Tools](#)





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Chapter 10.1: Data visualization and system integration

This chapter delves into user interface design, and system integration in SYMSITES, emphasizing the role of digital platforms in monitoring and optimizing I-US exchanges. Topics include the development of user-friendly dashboards, real-time data visualization, and seamless integration of industrial and municipal data streams. By enhancing digital interfaces, companies can improve decision-making efficiency and user experience in industrial applications.

- Target audience: Industry and SMEs
- Estimated time: 10 min
- Includes:

Explanations

Tools





Data Visualization and System Integration

In Industrial-Urban Symbiosis (I-US), digital integration and effective data visualization are critical for enabling industries and municipalities to monitor, manage, and optimize resource exchanges. Modern I-US systems rely on **real-time data acquisition, interoperable communication, and intuitive interfaces** to ensure that decision-makers can act promptly and efficiently.

Effective monitoring of energy, water, and material exchanges requires reliable connectivity between IoT devices, industrial processes, and data platforms, as well as the ability to interpret and act on information quickly. To succeed in this digital aspect of I-US, companies need to focus on securing interoperable systems, ensuring consistent and high-quality data, and designing intuitive visualizations and KPIs that make operational insights accessible and actionable. This approach enables SMEs and industries to make informed decisions, reduce inefficiencies, and maximize the benefits of symbiotic resource management.





Sensors and Actuators: The Core of I-US Digital Systems

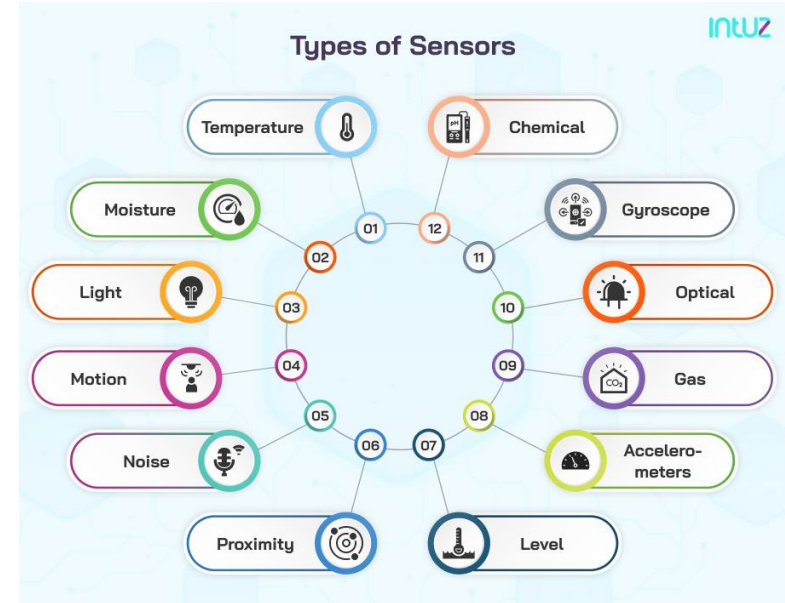
Sensors are the primary interface between the physical and digital layers of an I-US system. They detect environmental, chemical, or industrial parameters and convert them into data streams for real-time monitoring and analysis. Key characteristics include:

Compact and flexible: Sensors can be millimetres in size, allowing seamless integration into equipment or infrastructure.

Dual-level operation:

- **Physical level:** Measurement of defined indicators such as temperature, flow rate, pH, or pollutant concentrations.
- **Digital level:** Collection of quantitative data that can be transmitted, processed in real-time, or stored for later retrieval.

Continuous monitoring: Enables detection of anomalies, assessment of system performance, and informed decision-making.

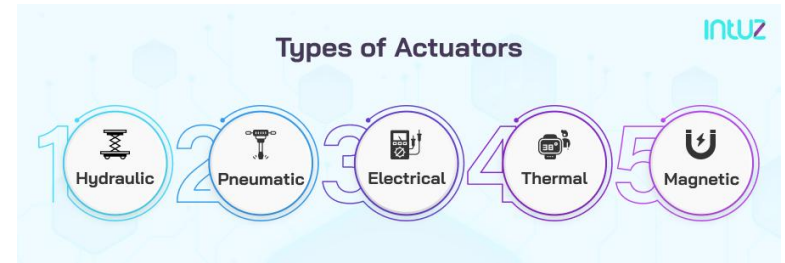




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Sensors and Actuators: The Core of I-US Digital Systems

Actuators complement sensors by translating digital commands into physical actions. They operate in the reverse direction of sensors, taking electrical input from control systems to manipulate valves, pumps, or mechanical equipment. Together, sensors and actuators form a **closed feedback loop**, allowing dynamic monitoring and automated responses across industrial processes.





System Integration and Interoperability

Digital integration in I-US requires connecting diverse devices and platforms, ensuring that data is **secure, consistent, and interpretable**. Two key principles enable this:

Semantic Interoperability: it ensures that I-US resource terms keep a stable and consistent meaning when information moves between different systems or platforms. Following NIST's guidance, it provides a shared vocabulary and clear definitions so that each system interprets data in the same way, regardless of how the data is stored internally. This reduces ambiguity, prevents errors during data exchange, and supports smoother integration of tools and services. By establishing a common semantic layer, organizations can align their models, simplify training, and improve communication between teams, ultimately enabling more reliable and efficient collaboration across diverse technical environments.





System Integration and Interoperability

Technical Interoperability is enabled by standardized communication protocols:

OPC UA (Open Platform Communications Unified Architecture) is a manufacturer- and platform-independent communication standard designed for industrial automation and control systems. It enables secure and reliable data exchange between devices, machines and enterprise systems. For example:

- It supports various communication models (client-server and publish/subscribe) and multiple transport protocols, giving it great flexibility for field devices, SCADA or cloud environments.
- It has built-in security: authentication, encryption, authorisation and data integrity, ensuring that networked industrial devices share data without compromising security.





System Integration and Interoperability

- It facilitates semantic data modelling: devices and machines expose their data in standard address spaces and information models, facilitating interoperability between equipment from different manufacturers.

Therefore, using OPC UA in an industrial-municipal resource exchange platform ensures that sensors, machines and IT systems share structured, meaningful data securely and reliably.

REST (Representational State Transfer) APIs are a widely used software architectural style for web services and networked systems. They enable different software systems to communicate via the HTTP protocol using standard methods. Key features:

- Each resource (e.g., a sensor reading, a machine status) is identified by a URL, and clients use HTTP methods such as GET, POST, PUT, DELETE to retrieve or modify resources.



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System Integration and Interoperability

- REST APIs follow the principle of statelessness: each request contains the necessary information, and the server does not maintain session state between requests, which improves scalability and simplicity.
- They are platform- and language-independent: any system that can make standard HTTP requests and process responses (usually JSON or XML) can be integrated.

In the context of I-US, REST APIs allow legacy systems, municipal databases, or web services to expose their data to a central platform, enabling flexible and decoupled integration, even if those systems are not designed for real-time industrial communication.

Using these standards, I-US platforms ensure **structured, meaningful, and secure data sharing** between sensors, industrial machinery, and municipal IT systems.



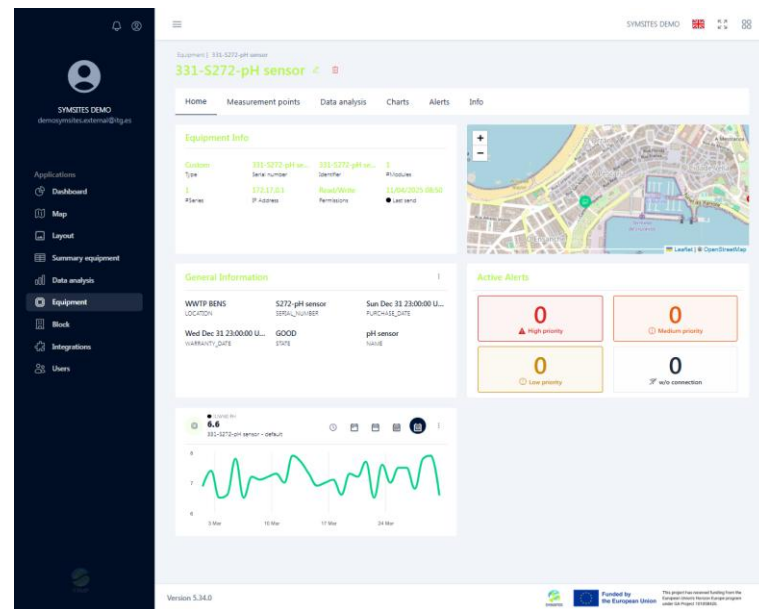


The SMC0 Module: Bridging Physical and Digital Worlds

The **SMCO module** within the SYMSITES ITRMP platform functions as the operational bridge between physical devices and digital analytics tools. Its key responsibilities include:

- **Device management:** Connecting, configuring, and authenticating sensors and actuators.
- **Data processing:** Applying basic validation, filtering, and formatting to incoming measurements.
- **Data registration:** Structuring data so that higher-level analytics, dashboards, and visualization tools can use it effectively.
- **Continuous monitoring:** Ensuring uninterrupted and accurate data streams for operational oversight.

By centralizing device management and data processing, SMC0 enables users to **transform raw sensor readings into actionable insights**.

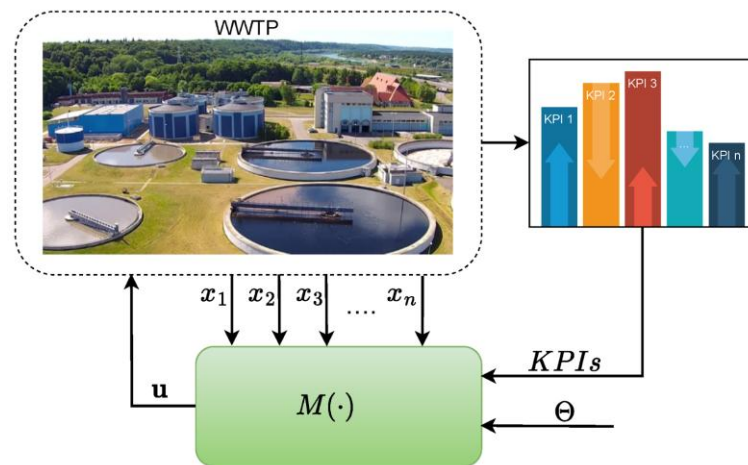




KPIs and User-Centered Visualization

A **Key Performance Indicator (KPI)** is a measurable metric summarizing the performance of an industrial or chemical process. KPIs are essential for tracking operational efficiency, environmental impact, and resource utilization (see module 7). Key points include:

- **Selection of KPIs:** Align indicators with operational goals and ensure they are measurable from reliable sensor data.
- **Composite indices:** Combine multiple metrics into weighted or normalized scores to provide a holistic performance view.
- **Validation:** Test KPIs through real or simulated plant applications to ensure they accurately reflect system performance.



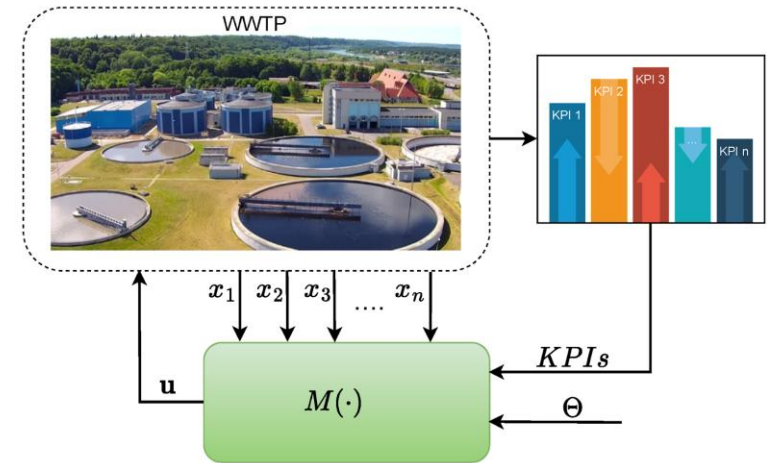


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KPIs and User-Centered Visualization

Integration into **dashboards and visualization tools** transforms complex process data into interpretable visuals:

- Graphs, trend charts, and tables allow users to track changes over time.
- KPI indicators help managers quickly identify deviations and take corrective action.
- Interactive dashboards improve **decision-making efficiency** and enhance user experience.



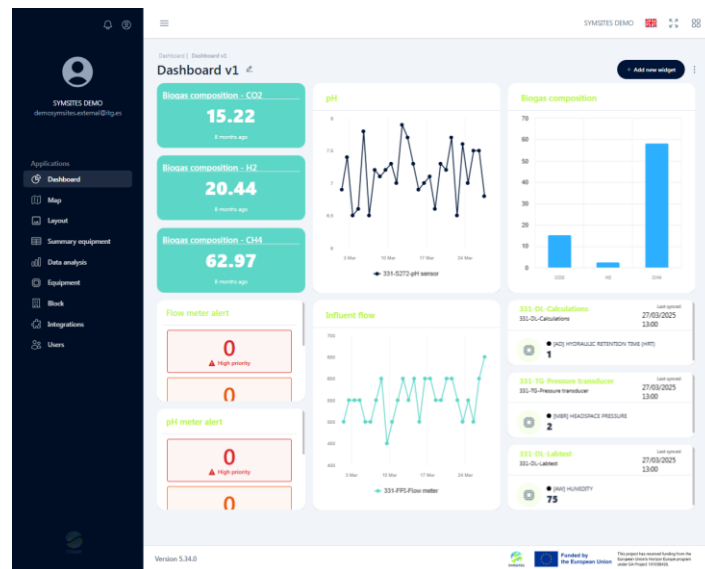


Creating Dashboards in ITRMP

To implement effective visualization in practice, learners can follow these steps to create an interactive dashboard using the SMC0 module:

- **Register in ITRMP:** Create an account at <https://devsymsites.itg.es>
- **Access SMC0:** Log in and open the SMC0 module.
- **Connect Sensors:** Register sensors, configure them, and confirm data transmission.
- **Open Dashboard:** Navigate to the dashboard tool within SMC0.
- **Add Widgets:** Include graphs, trend charts, tables, or KPI indicators as needed.
- **Review Layout:** Verify that data is displayed correctly and adjust for clarity and usability.

This workflow enables learners to **combine sensor data, KPI monitoring, and trend analysis into a single interactive dashboard**, providing real-time visibility into industrial processes and symbiotic resource flows.





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Chapter 10.2: Incorporating Real-Time Data Processing Tools

This final chapter covers incorporating real-time data processing tools, exploring how industries can leverage IoT sensors, AI-driven analytics, and automated monitoring systems to enhance resource tracking and process optimization. Real-time data enables early detection of inefficiencies, improves regulatory compliance, and supports adaptive management strategies for I-US partnerships.

- Target audience: Industry and SMEs
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Incorporating Real-Time Data Processing Tools

In I-US, industries and SMEs increasingly rely on **real-time data processing tools** to manage the continuous flows of resources, materials, and energy between industrial and urban systems. Real-time data collection and analysis transform traditional, static reporting into dynamic, data-driven decision-making, enabling faster responses to operational changes, early detection of inefficiencies, and proactive compliance with environmental and safety regulations.

For companies implementing I-US initiatives, real-time processing tools provide the foundation for digital visibility, operational resilience, and adaptive management. By integrating IoT sensors, analytics platforms, and AI-driven models, organizations can monitor the performance of resource exchanges, optimize internal processes, and improve coordination with municipal systems. SMEs and industries can approach real-time data processing as an operational enabler, embedding **analytics into everyday workflows** and using it to support economic and environmental objectives.



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Exploratory Data Analysis (EDA)

Exploratory Data Analysis (EDA) is a critical first step in understanding the complex datasets generated by industrial processes and IoT sensor networks. Originating from John Tukey's work, EDA allows operators and analysts to **identify trends, anomalies, and relationships** in data before applying predictive models or optimization strategies.

In practice, EDA in I-US involves:

- **Visualizing resource flows:** Graphical representations of water reuse, energy exchange, or by-product circulation help identify bottlenecks or inefficiencies.
- **Identifying anomalies:** Sudden spikes or drops in production variables or sensor readings can indicate equipment issues, process deviations, or contamination risks.





Exploratory Data Analysis (EDA)

- **Refining KPIs:** Analysis of raw data supports the selection of meaningful Key Performance Indicators that reflect operational and environmental objectives.
- **Interactive exploration:** Dashboards incorporating EDA allow operators to dynamically interact with datasets, test hypotheses, and adjust monitoring strategies in real time.

EDA bridges the gap between raw data and actionable intelligence, providing SMEs with insights into **process stability, resource efficiency, and potential improvements**.

2. Data Quality and Preprocessing

High-quality data is essential for effective monitoring and decision-making. Sensor networks and industrial systems often generate **incomplete, inconsistent, or noisy datasets**, which must be addressed before analysis.





Exploratory Data Analysis (EDA)

Key steps for managing data quality include:

Data cleaning: Detecting and correcting anomalies, outliers, or conflicting entries to ensure accurate trend analysis.

Data imputation: Estimating missing values using statistical methods such as mean, median, or regression models.

Time-series continuity: Applying interpolation, forward/backward filling, or smoothing techniques to maintain consistent records for trend analysis.

Validation at source: Implementing calibration, range checks, and consistency constraints directly at the sensor level to prevent erroneous data from entering the system.

Proper data handling ensures that KPIs, dashboards, and AI models operate on **reliable and actionable data**, reducing the risk of incorrect operational decisions.



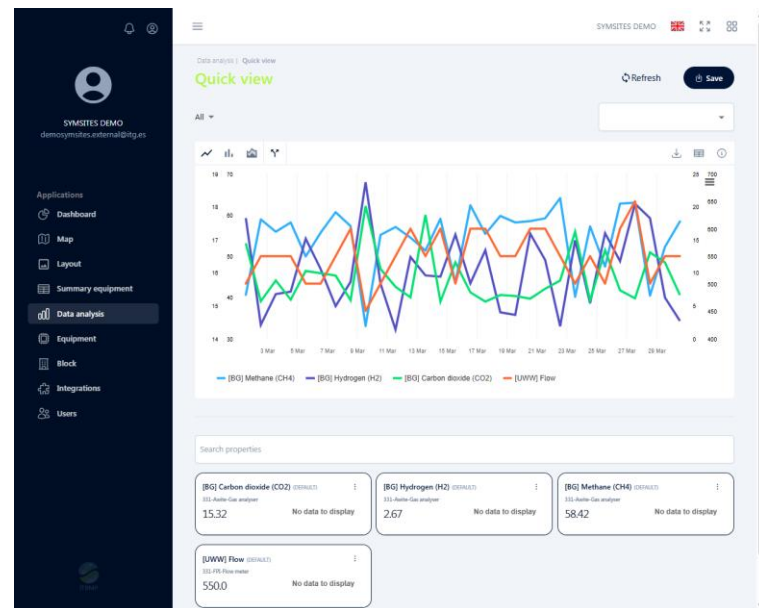


Real-Time Analytics and SMC0 Integration

The **SMC0 module in the SYMSITES ITRMP** serves as a central hub connecting physical sensors, actuators, and industrial-municipal data streams. It provides both operational management of devices and analytics capabilities, allowing SMEs and industrial operators to transform sensor data into meaningful insights (see chapter 10.1).

Key functionalities include:

- **Device management:** Registering, configuring, and authenticating heterogeneous sensors and actuators.
- **Data processing and validation:** Filtering, formatting, and structuring incoming measurements to ensure they are ready for analysis.
- **KPI computation and trend analysis:** Calculating energy efficiency, emissions, water reuse, or other operational metrics.





Real-Time Analytics and SMC0 Integration

- **Interactive dashboards:** Visualizing trends, anomalies, and key performance indicators to support decision-making.
- **Alerts and notifications:** Real-time flags when parameters exceed predefined thresholds, enabling immediate corrective action.

By integrating sensors, analytics, and visualization, SMC0 creates a **unified environment for continuous monitoring, operational optimization, and data-driven management** of industrial symbiosis activities.

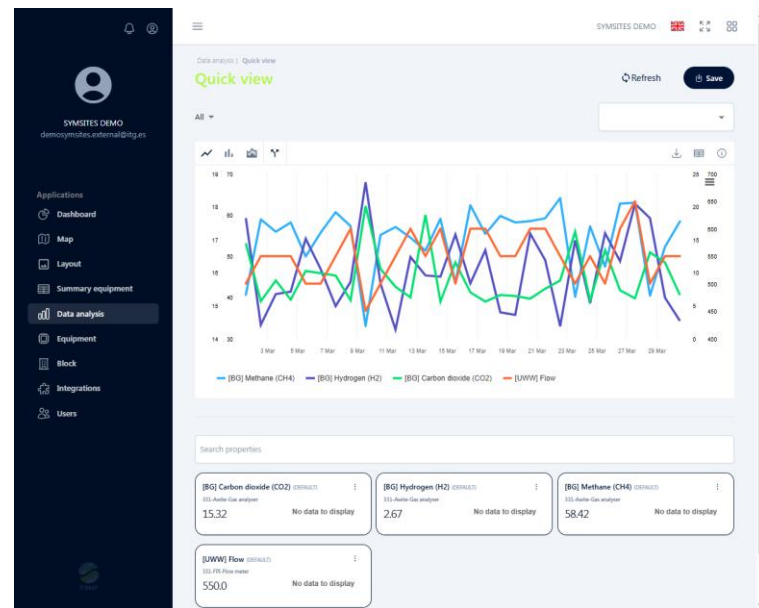
Key Performance Indicators (KPIs) and Dashboard Design

KPIs are central to monitoring performance in I-US projects. They condense complex operational data into actionable insights, enabling quick assessment of process efficiency and sustainability.

Design considerations for KPIs:

Align KPIs with operational goals, regulatory requirements, and sustainability objectives.

Base KPIs on **measurable, reliable sensor or process data**.





Real-Time Analytics and SMC0 Integration

Design considerations for KPIs:

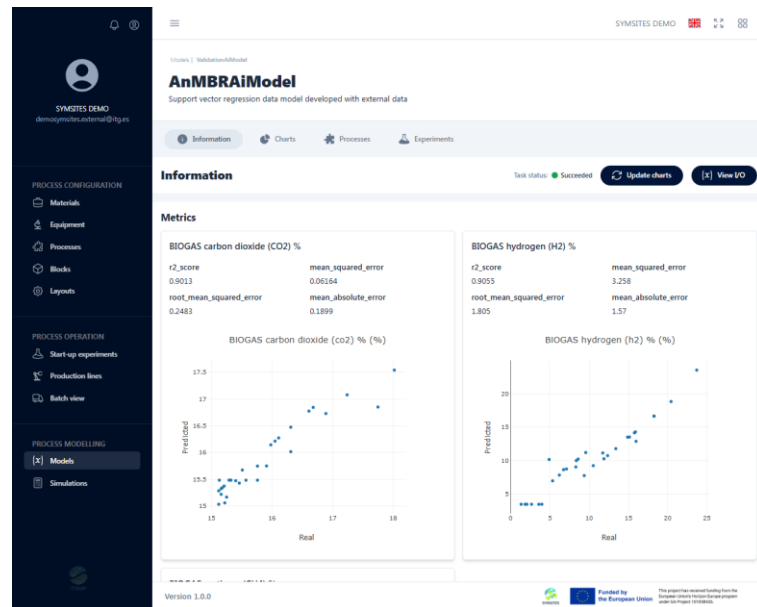
Align KPIs with operational goals, regulatory requirements, and sustainability objectives.

- Base KPIs on **measurable, reliable sensor or process data**.
- Consider **composite metrics** that combine multiple indicators, applying weighting or normalization as appropriate.
- Validate KPIs using historical data, simulations, or pilot-scale operations to ensure accuracy.

Effective dashboards integrate KPIs with real-time data visualization:

- Trend charts, heatmaps, and tables highlight performance over time.
- Comparative views allow benchmarking across facilities, processes, or resource flows.
- Interactive controls support dynamic filtering, scenario analysis, and drill-down into detailed process metrics.

For SMEs, dashboards provide an **operational “control center”** to monitor symbiotic exchanges and industrial processes simultaneously.



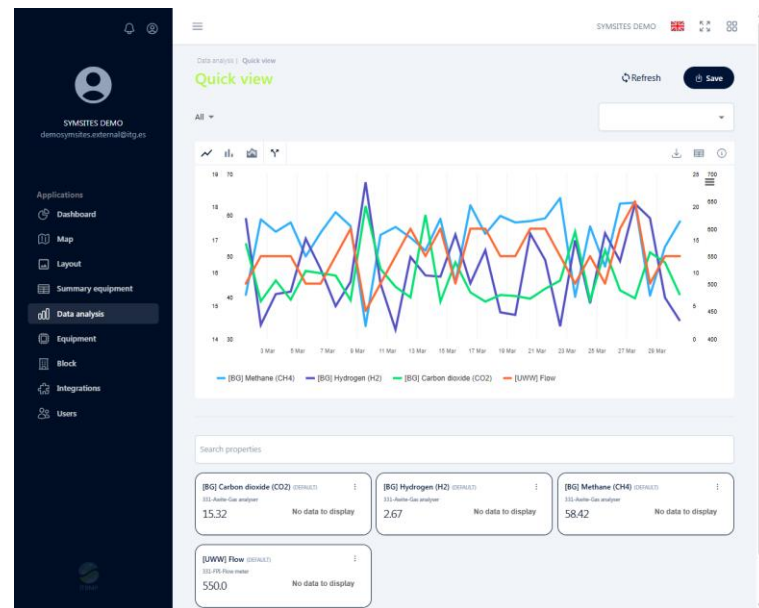


Tool: Data-centric programming

Python is a highly versatile and widely used programming language in scientific computing, data analysis, and process engineering due to its readability, flexibility, and rich ecosystem. Among its most powerful tools for data-centric work are:

- [NumPy](#): provides efficient N-dimensional arrays and mathematical operations, forming the foundation for numerical computing.
- [Pandas](#): builds on NumPy to offer high-level data structures (such as DataFrame) and tools for manipulating, cleaning, and analyzing tabular data.

Together, these libraries support a complete data-analysis workflow: from loading and cleaning raw sensor or process data, to exploratory analysis, KPI computation, trend detection, and data visualization. This makes Python a practical tool for monitoring, understanding, and optimizing industrial processes and operations.



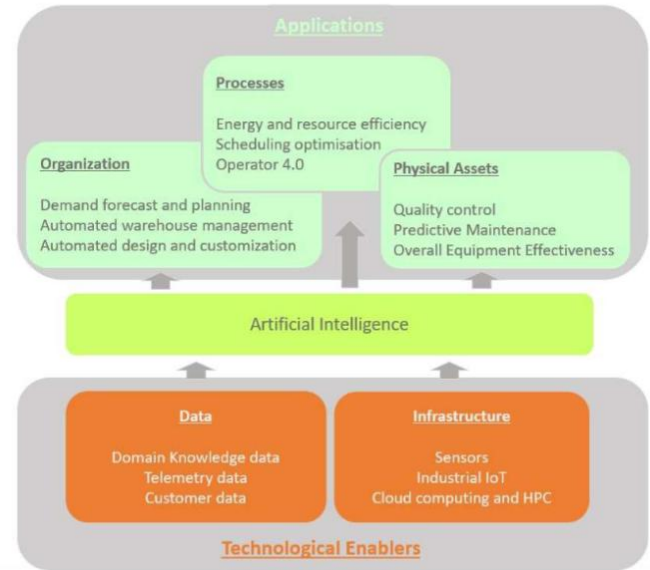


AI models for predictive and adaptive planning

According to the EU's AI Watch report "AI uptake in manufacturing", artificial intelligence plays a growing role in optimizing industrial operations by enabling more accurate resource forecasting and capacity planning. AI systems can integrate data from multiple production processes, factory floors, or sites, allowing manufacturers to predict resource needs, optimize equipment usage, and coordinate production schedules.

The report emphasizes that high-quality, accessible data is essential for AI to function effectively, and standardization of data formats and communication protocols is a key enabler for seamless data integration. By combining AI insights with human expertise, companies can make informed decisions about capacity allocation, production scaling, and operational adjustments, ultimately improving efficiency, reducing costs, and supporting strategic planning across manufacturing operations.

Figure 1. Mindmap of AI in Manufacturing





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AI models for predictive and adaptive planning

Artificial Intelligence (AI) extends the value of real-time data by providing **predictive insights and adaptive process management**:

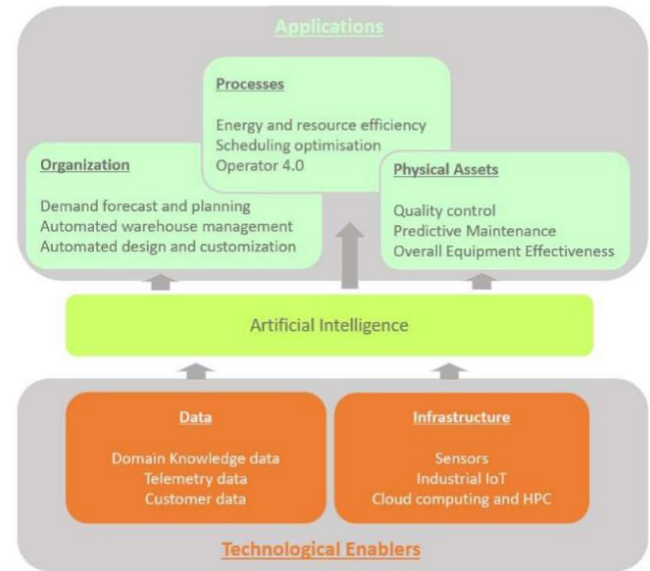
Resource forecasting: Predict water, energy, or raw material requirements across industrial and urban networks.

Process optimization: Simulate production scenarios, identify optimal operating points, and explore feasible regions for safe, efficient operation.

Real-time decision support: AI models can ingest live data and produce immediate projections, allowing proactive adjustments to processes.

Implementation tools: Libraries like **Scikit-learn** support machine learning algorithms for classification, regression, and clustering, suitable for predictive and adaptive planning.

Figure 1. Mindmap of AI in Manufacturing



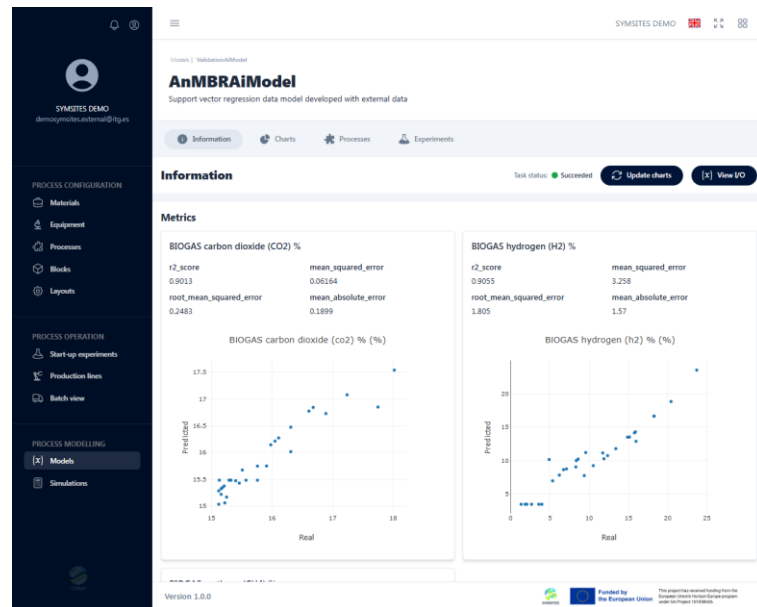


Regulatory Compliance and Monitoring

Real-time data processing plays a central role in maintaining **regulatory compliance**:

- **Continuous monitoring:** Track operational and environmental parameters to meet emissions, safety, and performance standards.
- **Automated alerts and interventions:** Notify operators immediately if limits are exceeded; integrate with control systems to adjust operations automatically.
- **Documentation and reporting:** Dashboards provide visual evidence of compliance, supporting audits and certification.
- **Closed-loop control:** Combines monitoring and process adjustments to maintain consistent adherence to regulatory thresholds.

This approach ensures that SMEs and industrial operators can maintain compliance without interrupting production, while reducing risk and improving resource management.





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CONSORTIUM MAP

