WP4 TASK 3

Advanced data-driven methods in Power-to-X operations

ABSTRACT

The main objective of the task was to apply artificial intelligence (AI) methods in Power-to-X (PtX) applications to enhance long-term renewable energy storage, hydrogen production, and methanol synthesis processes. The research focused on designing a comprehensive AI based infrastructure utilizing advanced technologies such as Internet of Things (IoT), big data analytics, edge computing and machine learning to optimize PtX operations. Key outcomes include an understanding of the role of AI methods in running PtX processes as a cyber-physical system, developing IoT-based architectures, selection of suitable IoT platform based on the PtX process requirements, employing machine learning models for operational parameter prediction, and integrating cybersecurity for secure hydrogen generation and storage.

MOTIVATION

Europe is leading the development of a sustainable energy system to reduce greenhouse gas emissions and achieve a green transition. Power-to-X (PtX) and cogeneration technologies are key to building a resilient, decentralized, and carbon-neutral energy network by 2050. These technologies offer huge potential for balancing electric grid loads, integrating renewable energy, and supporting the hydrogen economy. Utilizing innovative ICT tools PtX will enable more efficient energy storage and cross-sectoral integration, playing a crucial role in Europe's shift toward a reliable and cost-effective clean energy future.

RESULTS

Example of a PtX process is a synthetic CH4 (e-CH4) production system, a subset of PtX, that has a potential role e.g., as long-term energy storage. A primary process in e-CH4 systems involves converting hydrogen and carbon dioxide into methane (CH4), which can then be used as a substitute for natural gas. This methane can be stored or transported using existing natural gas infrastructure. Compared to short-term energy storage solutions such as batteries, e-methane provides long-term storage capacity and can smooth out fluctuations in energy supply caused by variable renewable energy generation.

Data driven methods in PtX

IoT technology enables the collection, transmission and processing of vast amounts of data from various points in the PtX process chain, including renewable energy generation, electrolysis, and chemical synthesis. This data is collected and analyzed to improve decision-making and grid management. IoT data is linked to several companies across industries, bringing challenges to store and analyse data, particularly in large and interconnected devices.

Big data analytics helps address the challenges posed by the massive amounts of data generated by IoT systems. By utilizing advanced analytics tools, organizations can extract valuable insights from structured, semi-structured, and unstructured data. In the context of PtX, big data analytics enables continuous improvement of plant operations by optimizing resource allocation, improving efficiency, and reducing downtime.

Machine learning plays a crucial role in predictive analytics, allowing PtX systems to improve operational efficiency by forecasting outcomes based on historical data. In the PtX context, machine learning algorithms are used to predict the best times for hydrogen production, storage, and utilization, minimizing the levelized cost of products such as methane. By training algorithms using historical data, the study showcases how machine learning models can predict future values more accurately and assist in optimizing system operations.

Figure 1 shows a theoretical architecture that integrates IoT, big data, and machine learning technologies.

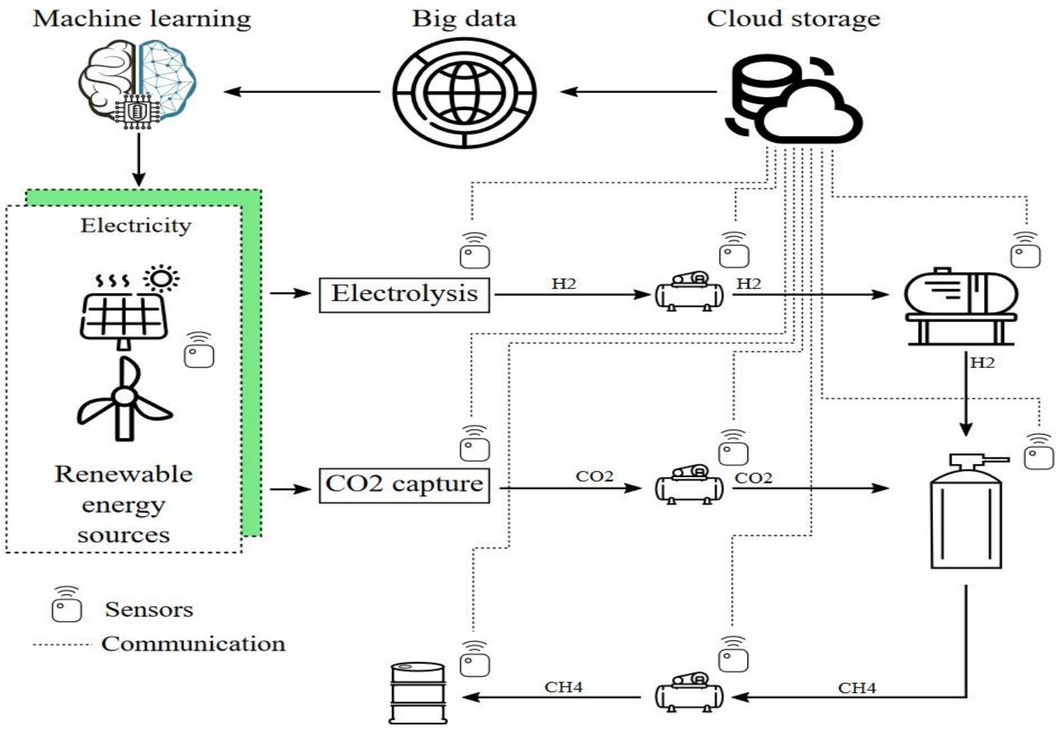

Figure 1. Main architecture designed for working of methanol synthesis.

The architecture involves four stages:

Data collection (IoT): Sensors are deployed across the PtX infrastructure to collect data related to renewable energy generation, electrolysis processes, CO_2 capture, and hydrogen/methane storage. ***Data storage****:* The collected data is stored in the cloud for subsequent processing. ***Big data processing****:* The stored data is processed using big data analytics tools to derive insights that can optimize system performance. ***Machine learning prediction****:* The processed data is used to train machine learning models that predict optimal operational parameters for the PtX system.

Based on this study, the major challenge for industries in implementing IoT and other latest technologies in Power-to-X (PtX) plant is the selection of the most appropriate Internet of Things (IoT) platform from the vast number of available options. The choice of an IoT platform is critical because it needs to be aligned with the unique requirements of PtX plants, which involve complex interactions between renewable energy sources, electrolysis, CO_2 capture, and fuel synthesis.

The research proposed a general framework as shown in figure 2 for IoT platform selection on PtX sector.

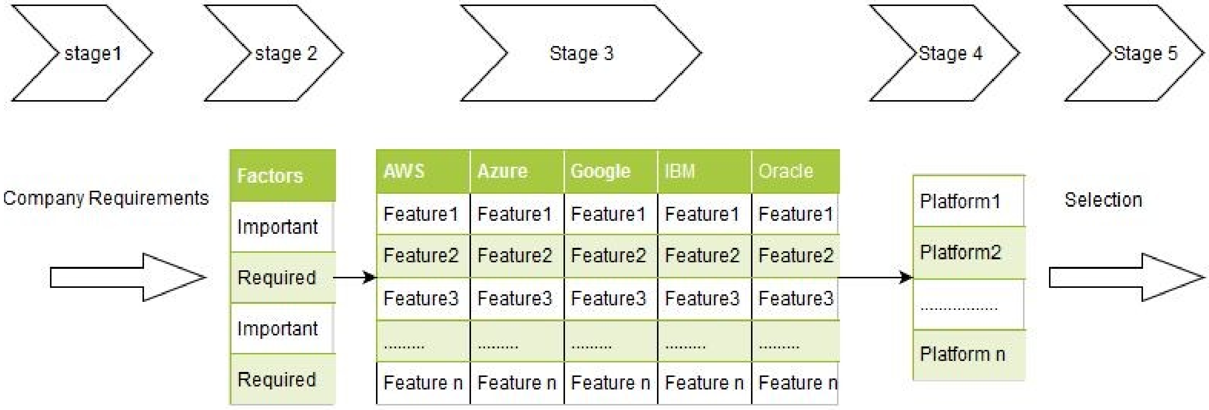

Figure 2: IoT platform selection Framework for PtX cogeneration plant

The framework provides an objective and systematic methodology to guide industries in selecting the most suitable IoT platform based on their operational needs. The use of this methodology in the framework ensures that the platform selection process is data-driven, transparent, and aligned with business goals.

The framework consists of five key stages. The *first stage* involves understanding the basics of IoT and how it supports the monitoring, data collection, and optimization of processes in the plant. The *second stage*, Identifies the plant's specific requirements, such as real-time data monitoring, energy storage management, and system automation. *Third stage* prioritizes these requirements as Required (R), Important (I), or Not Required (-) to focus on critical factors. This prioritization helps industries focus on the most critical factors when evaluating IoT platforms. In the *stage four*, the "Required" and "Important" factors are compared with the features of different IoT platforms**.** This comparison enables a more focused evaluation of which platforms can meet the essential requirements for the PtX cogeneration plant, narrowing down the options to those that are the best fit. In cases where multiple platforms satisfy all the requirements, the *final selection stage* is based on specific "Important" criteria, such as pricing, security etc.

APPLICATIONS and IMPACT

Implementing advanced data-driven technologies like IoT, big data, edge computing, and AI (machine learning) in PtX cogeneration plants offers significant benefits. First, these technologies enable the full digitalization of the plant's processes, from data collection to predictive analytics. Second, the new architecture using the latest innovations to enhance the efficient conversion of renewable energy into other forms that can be stored long-term and used when needed. The developed IoT platform selection framework ensures the selection of the IoT platform based on business needs.

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