P L A N E T 4

# IoT & ML for Reducing Energy Consumption

Monitor and improve the efficiency of production processes.

## The Challenge

*Energy prices are continuing to rise higher and higher. It is at the point where energy costs are comparable to the cost of raw materials. The company is a medium-sized enterprise consisting of several small food product manufacturers. They are faced with the challenge of needing to reduce their energy costs while maintaining production results.*

**Industry Sector:**
Manufacturing

**Challenge classification:**
Production optimization; Digital monitoring of production states; Green IIoT; Improve the cost-effectiveness and eco-friendliness of manufacturing processes.

**Time for Project Completion:**
N/A

### Main Requirements

- Monitor the production state.
- Identify the different sources of energy consumption.
- Recognize patterns in energy consumption.
- Automatically produce insights and analytics that can inform production decisions for reducing energy consumption.

### Other Requirements

N/A

### Key Performance Indicators

- Units produced.
- Energy saved (in kWh).

## Other information

N/A

# Research Phase

*Taking into account the challenge description, its requirements and its information, elaborate at least 5 questions that can lead your research for a solution.*

**Research questions:**

1. What depth or granularity of the manufacturing process does the company want to search for energy-saving opportunities? How does this impact the research direction of the solution?
2. How can the company improve the accuracy and efficacy of their current manual production monitoring?
3. How can the different sources of energy consumption be distinguished?
4. What kind of analysis can be done to help the company find energy-saving opportunities?
5. How can the solution be scaled across the company's different manufacturing environments?

*Given the questions and the main requirements of the challenge previously listed:*

- *identify possible technologies using the Planet4 Taxonomy Explorer;*
- *identify and analyze the sources (papers, articles, etc.) of those technologies that best suit the challenge;*

**Technologies identified in the taxonomy:**

1. Real-time Production and Process Monitoring Analysis and Supervision
2. Production Planning and Scheduling
3. Machine Learning
4. Data Visualization and Dashboarding
5. Data Analytics
6. Industrial IoT
7. Edge Computing
8. Sensors (Hardware)

## Sources of those technologies that best suit the challenge:

1. https://www.sciencedirect.com/science/article/pii/S2352484719308686
2. https://www.sciencedirect.com/science/article/pii/S2096232020300469
3. https://www.sciencedirect.com/science/article/pii/S0360544219309053
4. https://www.sciencedirect.com/science/article/pii/S0360544219310588
5. https://www.sciencedirect.com/science/article/pii/S0306261919318860
6. https://www.sciencedirect.com/science/article/pii/S0959652619335723
7. https://www.sciencedirect.com/science/article/pii/S0306261920309855
8. https://www.sciencedirect.com/science/article/pii/S2352484721015055
9. https://www.zerynth.com/customers/case-studies/real-time-production-performance-monitoring/
10. https://ifst.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/jfpp.14338
11. https://www.tandfonline.com/doi/abs/10.1080/0951192X.2022.2078511?journalCode=tcim20

*In light of the discoveries made:*

- *report the answers for the questions above;*
- *compare 2-3 of the more common solutions identified in the sources (how would they change the approach to the solution? What are the possible benefits/issues in such a use of these technologies?);*
- *draw initial conclusions on which path you want to take in proposing a solution.*

## Answers:

1. Many of the existing automatic solutions optimize the input parameters of machines (load for example) in order to reduce energy. While this specific granular focus can save energy, the case studies that examine higher-level changes to production schedules and equipment seem to find bigger opportunities to save, with less difficulty in execution. This level of focus means the solution will need to cater for combining many different data sources towards this goal, rather than being a single model for each machine to optimize.
2. Industrial IoT, edge computing and sensors, can facilitate data collection and smart analysis to improve production monitoring.
3. Manual data entry for identifying energy sources is one cheap solution, but this is flawed due to human error and behaviour in the face of such a monotonous task. Machine learning can be used to automatically find and use patterns in energy usage and/or sensor data to infer what product or machine is the source of energy usage. This in turn can enable nudges that simplify the user experience for this data entry.
4. Analysis can be as straightforward as pointing out unexpected sources of high energy usage. Bringing these points to the attention of decision-makers can enact informed change. Automation is not needed for acting out these changes as well. The suggestions or opportunities can be about finding scheduling changes such as moving load to an under-used machine or about replacing

high-usage tools or equipment that are outdated or overpowered for their purpose.

5. The final solution produced can be scaled across the company's subsidiaries by attempting to focus on generic and common data sources such as energy consumption, production time or machine temperature. Once the input is compatible, running the solution on an edge device can make deployment simpler and more scalable as well.

## Comparison:

The two main types of solutions found in the existing literature fall under are::

1. Individual models for machines
2. Manual expert analysis

The individual models are beneficial for finding the optimal parameters and state for existing equipment. However, the energy savings from this are limited and may not be worth the cost or change in production levels. Manual expert analysis is excellent at finding the best possible savings opportunities for the business while maintaining production levels. But, this method is time-consuming, expensive and does not scale well across the subsidiaries in different environments.

Finding a middle ground between the two could be the ideal solution for finding meaningful energy-saving opportunities while maintaining scalability and reasonable cost. The drawbacks of this approach would be the system becomes more complicated than an individual model and it does not find the same quality or uniqueness as a manual expert. The benefits compared to the two extremes however make it a worthwhile approach.

## Conclusions:

To meet the need of reducing energy consumption for a medium-sized enterprise made up of smaller food product manufacturers, there are two current approaches in the existing literature. The first uses machine learning and optimization algorithms to find the optimal input parameters and state of production equipment. This is scalable and uses a simple architecture of only one model, but the savings opportunities are limited. The second uses some degree of IoT data collection and then revolves around manual expert data analysis to find the most meaningful and tailored energy-saving opportunities. This is the ideal in terms of the quality of results, but is expensive, time-consuming and does not scale well across the subsidiaries without the higher cost.

We think the best approach to meeting the needs of the company would be leveraging some of the benefits of each current method. That is, a method based on multiple models for understanding the state of the production, finding patterns in consumption and highlighting that information for decision-makers to act on. This solution can be encapsulated on an edge device to increase scalability and convenience of deployment in new environments.

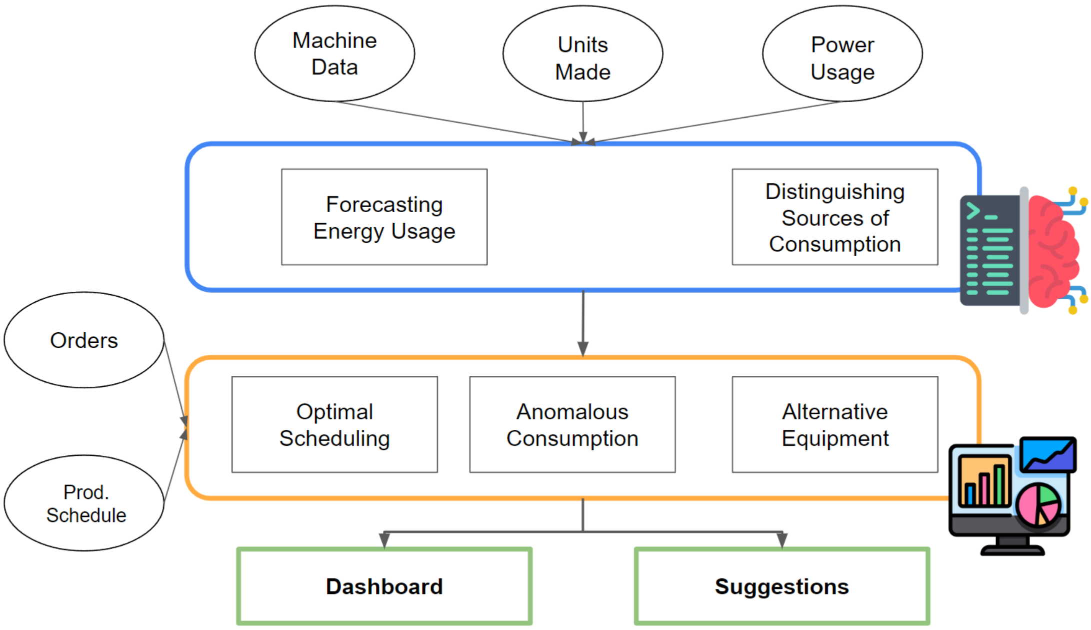
# Proposed Solution

*Making use of the technologies identified after the analysis of the sources, describe a possible solution to the challenge. Also, do not forget the constraints (time, number of devices to produce/connect, etc.): the solution must be applicable to the real context of the company that commissioned the challenge.*

## Solution Summary

*Brief description of the solution (1-2 paragraphs + 1 image)*

The proposed solution seeks to balance scalability and quality of suggestions. It, therefore, comprises two major components: 1) a layer of ML models for converting machine data and industry management information into a holistic digital representation of the production state. 2) an analytics layer that deduces points of interest for decision-makers.



## Solution Description

*Describe the solution and its details*

The solution would take the following sources as input to the ML layer:

- common machine sensor data (time cycles, power usage, temperature)
- ERP data (order quantities, production quantities)

The layer would produce forecasted energy usage through an RNN and estimate connections between consumption and products. It would then provide this information to the analytics layer. That layer would receive the following:

- estimated future power usage (from ML)
- current power usage by product and machine (from ML)
- production schedules

It would then produce a dashboard of charts and statistics around the energy used and units produced. Based on this, rules can be set to present suggestions if certain circumstances or thresholds are met. These suggestions will be around ensuring machines are being used efficiently according to the energy they consume rather than just time or load. The suggestions are presented alongside the dashboard so all of the information needed is available concisely to decision-makers.

## Implementation Plan

*Describe the solution implementation plan considering among other things: gantt chart with milestones, high-level cost analysis, possible difficulties (at least 3 major issues or difficulties) and additional opportunities (at least 2 extra benefits).*

A possible implementation plan for the solution could be as follows.

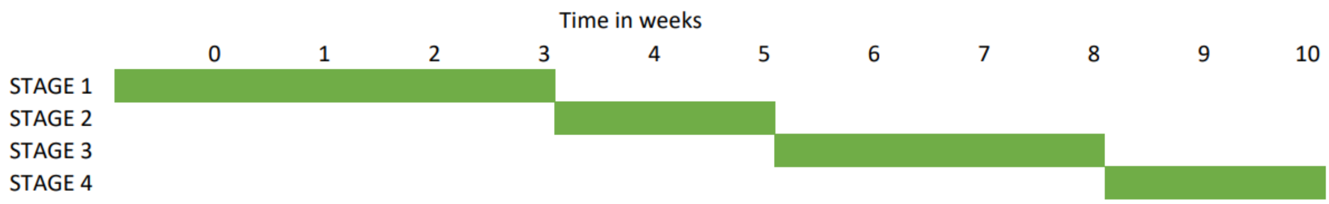
STAGE 1: Curation of data sources. The input sources mentioned for the ML models are common variables but as the company exists only within the food manufacturing space, any others that are consistent across subsidiaries could be added. If no existing means of collecting this data is in place, this stage would also include deployment and collection. The final datasets collected will be used for training the models.

STAGE 2: Training models. The model for forecasting energy consumption will not need any labelling as the ground truth is simply the future value. The model for identifying products and machines as a source of energy consumption would need labelling which is to be done in this stage as well.

STAGE 3: Analytics. The analytics based on the different data sources and ML inferences will be done in Python for statistics like which products consume the most energy per unit, patterns of underused machines, usage over time, how usage changes according to the level of demand in orders or any other points of interest the company may have.

STAGE 4. Deployment and testing. Deployment would include integration with live data sources and testing the ability of the system to continuously monitor for energy-saving opportunities. The deployment of the models would be onto an edge device for easy scaling.

**Gantt chart:**




**High-level cost analysis**

| | |
|---|---|
| Data collection hardware and labelling | 1,000 € |
| Machine learning project and development | 15,000 € |
| Analytics development | 8,000 € |
| TOTAL | 24,000 € |

Possible difficulties:

1. There can be a lack of data or means of collection available which would prolong the first stage.
2. It may be challenging to decouple individual products in a machine's usage.
3. The resource constraints of an edge device could limit the solution's performance.

Possible benefits:

1. In scaling the solution across subsidiaries, the company can consider providing the solution to other companies as well.
2. The data collection set in place can act as a foundation for further innovation.
3. Unlike a tailored solution which is a one-off high-quality consultancy, the solution would remain continuously monitoring the company as they continue to change and evolve.