AI-Driven Energy Management System for Small and Medium Manufacturing Units

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22-08-2024

ABSTRACT

The "AI-Driven Energy Management System for Small Manufacturing Units" project aims to create an affordable, scalable solution to optimize energy use in small to medium-sized manufacturing environments. Recognizing that energy costs significantly impact operational expenses, this system leverages AI and IoT to fill the gap left by complex and costly existing solutions. IoT-enabled sensors monitor real-time energy usage, feeding data into an AI engine that analyzes patterns, detects inefficiencies, and offers optimization recommendations. The system considers external factors like energy prices and weather to provide context-aware, actionable insights for reducing energy waste.

1. Problem Statement

Small and medium-sized manufacturing units face significant challenges in managing energy costs, which often account for a large portion of their operational expenses. Many existing energy management systems are designed for large-scale operations and are too costly and complex for smaller businesses. This leaves small manufacturers without the tools they need to monitor and optimize their energy usage effectively.

The lack of real-time energy monitoring leads to inefficiencies, such as machines operating during peak energy pricing or running at suboptimal settings. These inefficiencies result in higher costs, increased energy waste, and a larger carbon footprint, making it difficult for these businesses to meet sustainability standards.

Additionally, small manufacturers often lack the technical expertise and resources to implement complex energy management solutions, exacerbating the problem. There is a clear need for an affordable, easy-to-use energy management system tailored specifically to small and medium-sized manufacturing units. This system should provide real-time insights, leverage AI and IoT for automation, and help these businesses reduce costs, improve efficiency, and enhance sustainability.

2. Market/Customer/Business Need Assessment

2.1. Market Analysis

The market for energy management solutions is growing rapidly, driven by increasing energy costs, stricter environmental regulations, and a global push toward sustainability. However, much of the current market is focused on large industrial operations, leaving a significant gap in solutions tailored to small and medium-sized manufacturing units. These businesses, which make up a substantial portion of the global manufacturing sector, are often underserved by existing energy management products due to their complexity and high costs.

Small and medium-sized enterprises (SMEs) in the manufacturing sector account for a considerable share of global economic activity. In the U.S. alone, SMEs make up 98.6% of all manufacturing firms, highlighting the vast potential market for a solution that meets their specific needs. Similar trends are observed in Europe and Asia, where small manufacturers are crucial to the economy but face challenges in managing operational costs, particularly energy expenses.

2.2. Customer Segmentation

To effectively target the proposed AI-Driven Energy Management System, it’s crucial to understand and segment the potential customer base within the small and medium-sized manufacturing sector. This segmentation will help tailor the product features, marketing strategies, and pricing models to meet the specific needs of each segment. Below are the key customer segments:

2.2.1. Micro Manufacturers

These are small-scale manufacturing units, often family-owned or operated by a small team of fewer than 10 employees and produce goods in limited quantities or operate as specialized suppliers within a niche market. Energy consumption is generally low to moderate, with a few key machines or processes driving most of the usage with no automation. Simple, low-cost energy monitoring solutions that can be easily implemented without requiring significant technical expertise.

2.2.2. Small Manufacturers

These businesses have between 10 and 50 employees and often serve as local or regional suppliers and operate with a moderate level of machinery. Moderate to high energy consumption, with multiple machines and processes contributing to overall usage.

2.2.3. Medium-Sized Manufacturers

These companies have between 50 and 250 employees and often have multiple production lines or facilities. They may operate in highly competitive markets, requiring efficient and cost-effective production processes. Greater complexity in energy management due to the scale of operations and the need to balance energy use with production demands.

2.2.4. Niche Manufacturers

These are specialized manufacturers that produce unique or high-value products, often in small batches. Examples include precision engineering firms, artisanal goods producers, and bespoke product manufacturers. Energy efficiency is often critical due to the high cost of production and the need for precision and reliability.

2.2.5. Green or Sustainable Manufacturers

These manufacturers prioritize sustainability and environmentally friendly practices as core components of their business model. They often market their products as eco-friendly and may be subject to strict environmental regulations.

3. Target Specification

3.1. Market Analysis

3.1.1. Business Size

Micro Manufacturers (1-10 employees)
Small Manufacturers (10-50 employees)
Medium-Sized Manufacturers (50-250 employees)

3.1.2. Energy Consumption Patterns

Low to Moderate Consumption
Moderate to High Consumption
Variable Consumption

3.1.3. Technical Expertise

Low Technical Expertise
Moderate Technical Expertise
High Technical Expertise

3.1.4. Budget Constraints

Cost-Sensitive
Value-Oriented
Investment-Ready

3.1.5. Operational Priorities

Efficiency Focused
Cost Reduction Focused
Sustainability Focused

3.1.6. Geographical Location

Urban Manufacturers
Rural Manufacturers
Global Reach

3.2. Core functionality

3.2.1. Real-Time Energy Monitoring

Provide continuous, real-time tracking of energy consumption across all connected machinery and production lines. IoT-enabled sensors to monitor energy usage at the machine level.
Benefits: Enables manufacturers to detect and address energy inefficiencies immediately, reducing waste and preventing costly downtime.

3.2.2. AI-Driven Energy Optimization

Use AI to analyze energy consumption patterns and provide recommendations to optimize energy use. Machine learning algorithms that analyze historical and real-time data to identify trends and inefficiencies.
Benefits: Helps manufacturers reduce energy costs by optimizing usage based on data-driven insights like weather conditions and off-peak hours scheduling.

3.2.3. User-Friendly Interface

Ensure the system is accessible to users with varying levels of technical expertise. Intuitive, customizable dashboard that can be accessed via web or mobile applications.
Benefits: Lowers the barrier to adoption by making the system easy to understand and use, even for non-technical users.

3.2.4. Scalability and Flexibility

Allow the system to scale with the growth of the manufacturing unit and adapt to changing needs. Ability to handle varying levels of data complexity, from simple monitoring to advanced predictive analytics.

Benefits: Ensures the system remains relevant and useful as the business grows and evolves.

3.3. Performance Requirements

3.3.1. Real-Time Data Processing

The system must be capable of processing and displaying energy consumption data in real-time, with minimal latency. Data refresh rate should be within 1-5 seconds to ensure timely monitoring. Capable of handling data from multiple sensors simultaneously without degradation in performance.

3.3.2. Accuracy of AI-Driven Recommendations

The AI algorithms must provide highly accurate energy optimization recommendations, with a precision rate of at least 90%. The system should incorporate historical data, machine learning models, and real-time inputs to predict energy usage and recommend adjustments.

3.3.3. Scalability

The system should be able to scale from small operations with a few machines to medium-sized manufacturing units with multiple production lines. The system architecture should support adding new sensors, machines, or even additional facilities without significant reconfiguration.

3.3.4. Integration Capability

The system must integrate seamlessly with existing enterprise systems, such as ERP (Enterprise Resource Planning) and MES (Manufacturing Execution Systems). Ensure data compatibility and synchronization with other systems without requiring extensive customization.

3.3.5. Sustainability and Compliance

The system must support sustainability initiatives and help manufacturers comply with relevant energy regulations. Support the manufacturer's sustainability goals and ensure adherence to environmental regulations.

3.3.6. Data Security and Privacy

The system must maintain high standards of data security and privacy, protecting sensitive operational data from unauthorized access. Protect the manufacturer’s data integrity and prevent security breaches that could compromise operations.

4. External Research

4.1. About it

Designing an AI-driven Energy Management System for small and medium-sized manufacturing units requires thorough external research. Key industry trends, such as the increasing focus on sustainability and the adoption of Industry 4.0 technologies, suggest that the system should include features for real-time energy optimization, carbon footprint tracking, and decentralized energy management. Analysis of the competitive landscape reveals a gap in affordable, user-friendly energy management solutions tailored to SMEs. Partnering with IoT providers and leveraging AI frameworks and cloud computing can enhance the system's performance. Understanding customer needs and regulatory requirements will ensure that the system is both effective and compliant.

4.2. Analysis of Existing Platforms or Methods

4.2.1. Traditional Energy Management Methods

Manual Monitoring and Control- Many small and medium-sized manufacturers use manual methods to monitor and control energy usage, relying on basic metering devices and manual logging. This approach is low-cost and simple, requiring no advanced technical skills or expensive infrastructure. However, it is labor-intensive, prone to human error, and lacks real-time data, leading to delayed responses to energy inefficiencies. Additionally, it fails to provide detailed insights or predictive analytics and is limited in scalability as operations grow.

Time-of-Use (TOU) Tariffs - Time-of-Use (TOU) tariffs allow manufacturers to optimize energy consumption by adjusting production schedules to align with lower-cost energy periods, leading to potential cost savings. This method is simple to implement with a basic understanding of energy pricing structures. However, it offers limited flexibility, as shifting production schedules may not always be feasible. TOU tariffs do not address overall energy efficiency, provide insights into specific energy wastage areas, or offer real-time optimization based on dynamic energy demand changes.

4.2.2. Existing Energy Management Software

Building Energy Management Systems (BEMS) - Building Energy Management Systems (BEMS) monitor and control energy use in large facilities. They offer centralized control, automation, and real-time data visualization, and can integrate with other systems like HVAC. However, BEMS have high upfront costs, complex setup, and maintenance, and are primarily designed for large-scale operations, making them less accessible and scalable for smaller manufacturers.

Enterprise Energy Management Systems (EEMS) - Enterprise Energy Management Systems (EEMS) manage energy consumption across multiple sites for large corporations. They offer advanced features like predictive analytics, energy forecasting, and carbon tracking, integrating with other enterprise systems. However, EEMS are expensive, complex, and require significant technical expertise, making them impractical and overkill for small and medium-sized manufacturers with simpler energy management needs.

4.2.3. AI-Based Energy Management Solutions

Industrial AI Platforms - Advanced AI platforms like Siemens' MindSphere or GE's Predix include energy management within broader industrial IoT and AI solutions. They offer powerful predictive analytics and machine learning, optimizing energy use and providing a comprehensive view of operations. However, these platforms are expensive and complex, requiring significant infrastructure and expertise, making them more suitable for large-scale industrial applications and less accessible or necessary for small and medium-sized manufacturers.

Cloud-Based Energy Management Platforms - Cloud-based platforms like Enel X and Schneider Electric’s EcoStruxure offer scalable, accessible energy management solutions using cloud computing. They provide real-time monitoring, analytics, and optimization with lower upfront costs through subscription pricing. However, subscription costs can add up, reliable internet is essential, and the complexity may still pose challenges for smaller manufacturers without dedicated IT support.

5. Constraints and Regulations

5.1. Constraints

5.1.1. Budget Constraints

SMEs typically operate with limited financial resources, so energy management systems must be affordable. Cost-effective solutions could involve using opensource software, affordable IoT sensors, and cloud-based platforms. Offering subscription-based pricing or pay-as-you-go plans can help manage costs effectively while ensuring a clear return on investment.

5.1.2. Technical Expertise

SMEs often lack specialized technical expertise in AI, machine learning, and IoT, requiring systems that are user-friendly and easy to manage. Comprehensive support, straightforward documentation, and possibly remote management services will be crucial to ensure smooth implementation and operation, minimizing the need for dedicated IT staff.

5.1.3. Space Constraints

Manufacturing units with limited physical space require compact, easily integrated hardware solutions. Opting for cloud-based data processing and storage can minimize the need for on-site infrastructure, making the system more adaptable to space constraints without sacrificing functionality.

5.1.4. Data Privacy and Security

Handling sensitive operational data necessitates stringent privacy and security measures. The system must feature robust security protocols like encryption and secure data transmission, ensuring compliance with data protection laws such as GDPR or CCPA, to protect SMEs' data in cloud-based environments.

5.1.5. Scalability

As manufacturing units grow, their energy management needs will evolve. The system should be scalable, allowing easy integration of new sensors, data points, and features without requiring significant reconfiguration or investment, ensuring it grows alongside the business.

5.1.6. Integration with Existing Systems

The energy management system must seamlessly integrate with existing legacy systems, such as industrial control systems or ERP software. Compatibility with standard industrial communication protocols like OPC UA or Modbus ensures smooth integration and operation within the existing infrastructure.

5.2. Regulations

5.2.1. Energy Efficiency Regulations

Energy efficiency regulations require manufacturers to monitor and report energy consumption, often adhering to specific standards. The system should include automated monitoring, reporting tools, and efficiency recommendations to help manufacturers comply with these regulations effectively.

5.2.2. Environmental Regulations

Manufacturing units must comply with environmental regulations to minimize emissions and waste. The system should track energy-related emissions and provide insights to reduce the unit's environmental footprint, offering features that optimize energy use and contribute to emission reductions.

5.2.3. Occupational Health and Safety Regulations

Energy management systems must comply with occupational health and safety standards to ensure worker safety. The system's design should prioritize safety, incorporating fail-safes and intuitive interfaces that reduce the risk of human error and mitigate potential hazards associated with system failures.

5.2.4. Data Protection and Privacy Regulations

Compliance with data protection laws is crucial, particularly for cloud-based systems. The system must incorporate encryption, data minimization, and user control measures to safeguard personal and operational data, ensuring full compliance with relevant data protection regulations.

6. Monetization

6.1. Subscription-Based Model (Software-as-a-Service - SaaS)

The monetization strategy involves a tiered subscription model tailored to manufacturing unit size, connected devices, or feature levels. The Basic Plan offers essential energy monitoring and reporting at an affordable price, ideal for small businesses. The Standard Plan includes predictive maintenance, basic AI-driven optimization, and ERP integration, targeting medium-sized businesses. The Premium Plan provides advanced AI-driven optimization, real-time analytics, comprehensive compliance reporting, and dedicated support. This approach ensures predictable revenue, affordability for SMEs, and scalability to meet growing customer needs.

6.2. Pay-Per-Use Model

The Pay-Per-Use model offers an alternative or complement to subscription plans by charging customers based on their actual usage of energy management features like report generation, AI-driven optimizations, and data monitoring. The pricing structure includes charges for energy optimization services, data analytics, and on-demand consulting. This model provides flexibility, allowing customers to pay only for what they use, which is appealing for cost-conscious SMEs. It also lowers the entry barrier, making it easier for customers to start using the system.

6.3. Hardware Sales or Leasing

Hardware Sales or Leasing involves selling or leasing proprietary IoT sensors and other hardware components. Direct sales allow customers to purchase these devices outright, while leasing spreads the cost over time, making it appealing to SMEs. Leasing agreements can include maintenance and support, and bundling hardware with software subscriptions creates an all-inclusive service package. This approach provides an additional revenue stream through upfront sales or recurring leasing income, with bundling opportunities enhancing customer retention.

6.4. Freemium Model with Paid Upgrades

Freemium Model with Paid Upgrades provides customers with a basic version of the energy management system for free, encouraging widespread adoption by lowering the initial barrier to entry. The free version includes essential features like basic energy monitoring and standard dashboards. Customers can choose to purchase premium features, such as AI-driven optimization, detailed analytics, and compliance reporting, as paid upgrades. This model allows for quick customer acquisition and creates opportunities for upselling premium features once users recognize the value of the system.

7. Benchmarking Alternative products and Applicable Patents

7.1. Benchmarking

7.1.1. Schneider Electric EcoStruxure™ Power

Schneider Electric's EcoStruxure™ Power is a robust energy management platform designed for industrial environments. It integrates IoT, AI, and big data to deliver real-time energy monitoring, predictive maintenance, and optimization. The platform is known for its comprehensive feature set and compliance with international energy standards, making it ideal for large enterprises. However, its high cost and complexity may pose challenges for small to medium-sized enterprises (SMEs) that lack the necessary technical expertise. While Schneider Electric's strong brand reputation adds credibility, the platform might be over-engineered for smaller operations.

7.1.2. Siemens Energy Management Solutions

Siemens' energy management solutions, including the SIMATIC Energy Manager, provide detailed energy consumption analysis and AI-driven insights to optimize industrial energy use. The platform is highly integrated with Siemens' automation systems and is scalable, making it adaptable for industries of various sizes. Despite these strengths, the solutions require a high initial investment, which may be prohibitive for SMEs. Additionally, integrating the system with existing infrastructure can be complex and may require significant customization, posing challenges for smaller businesses with limited technical resources.

7.1.3 Honeywell Energy Management System

Honeywell's Energy Management System offers real-time energy monitoring, control, and optimization across industries. It utilizes IoT devices and AI to deliver actionable insights, with user-friendly dashboards making it accessible to non-experts. Honeywell is also known for its strong customer support, a critical factor for SMEs. However, the platform's limited customization options may not meet the needs of more complex operations. While it is more affordable than some competitors, the cost could still be a barrier for smaller SMEs, limiting its appeal to cost-sensitive businesses.

7.2. Patents applicable

7.2.1. Patent Title: Energy Management System for Monitoring and Controlling Energy Usage in Industrial Settings

Assignee: Schneider Electric

This patent covers methods and systems for monitoring and controlling energy usage in industrial environments using IoT sensors and predictive analytics. It includes the use of AI to optimize energy consumption based on real-time data.

The proposed system may utilize similar methodologies for monitoring and AI-driven optimization. However, focusing on SMEs and implementing specific cost-effective and user-friendly approaches can differentiate it and potentially avoid infringement.

7.2.2. Patent Title: Intelligent Energy Management System Using Machine Learning

Assignee: Honeywell International Inc.

This patent covers an intelligent energy management system that leverages machine learning to adaptively optimize energy usage in real-time based on changing conditions within an industrial setting.

The machine learning aspect of the proposed system needs careful consideration to ensure it does not infringe on this patent. Focusing on specific use cases, such as small-scale manufacturing, and employing unique machine learning models could offer a pathway to innovation without infringement.

8. Concept generation

8.1. Modular Design Approach

Develop the energy management system as a modular platform where different functionalities (monitoring, optimization, reporting, compliance, etc.) are offered as separate modules. SMEs can choose and pay for only the modules they need.

This approach provides flexibility and cost-effectiveness, allowing SMEs to customize the system according to their specific requirements and budget constraints.

Start with core modules like real-time energy monitoring and basic reporting. Additional modules, such as AI-driven optimization and predictive maintenance, can be added as needed.

8.2. AI-Driven Predictive Maintenance

Integrate an AI-driven predictive maintenance feature that uses machine learning to predict equipment failures before they happen. This could be based on patterns identified in energy usage data.

Predictive maintenance helps reduce downtime and repair costs, which are critical concerns for SMEs with limited resources.

Use historical energy consumption data to train machine learning models. The models would predict when specific equipment might fail, allowing maintenance to be scheduled proactively.

8.3. IoT-Enabled Real-Time Monitoring

Incorporate IoT sensors that provide real-time monitoring of energy consumption across different parts of the manufacturing facility. These sensors feed data into the central system for analysis and optimization.

Real-time data is essential for accurate monitoring and timely decision-making, especially in dynamic manufacturing environments.

Develop or partner with a manufacturer for IoT sensors that are cost-effective and easy to install. Ensure they are compatible with the system's data processing and AI components.

8.4. Automated Compliance Reporting

Include an automated compliance reporting feature that generates reports based on local and international energy regulations. The system should automatically adapt to new regulations as they are implemented.

SMEs often struggle to keep up with complex regulatory requirements. Automated reporting reduces the burden of compliance and ensures that businesses avoid penalties.

Integrate a database of relevant regulations into the system. The AI component can monitor changes in regulations and update reporting templates accordingly.

8.5. Energy Efficiency Optimization Algorithms

Develop advanced algorithms that not only monitor energy consumption but also provide actionable recommendations for optimizing energy use. These could include suggestions for scheduling machinery operations during off-peak hours or using alternative energy sources.

Energy efficiency directly impacts cost savings, which is crucial for SMEs. Providing actionable insights based on data can significantly reduce energy expenses.

Use a combination of historical data, real-time monitoring, and AI to develop optimization algorithms that continuously learn and improve over time.

9. Final Product Prototype

9.1. Key Features

Modular Design: The system is composed of various modules that can be selected based on the specific needs of the business. Core modules include energy monitoring, AI-driven optimization, predictive maintenance, and automated compliance reporting.

Real-Time IoT Monitoring: IoT sensors placed throughout the manufacturing facility provide continuous real-time data on energy consumption. This data is used to monitor and analyze energy usage patterns.

AI-Driven Predictive Maintenance: The system uses machine learning algorithms to predict potential equipment failures based on energy consumption data, allowing for timely maintenance and reducing downtime.

User-Friendly Dashboard: The system features an intuitive, customizable dashboard that presents key energy metrics, alerts, and recommendations in a clear and accessible format.

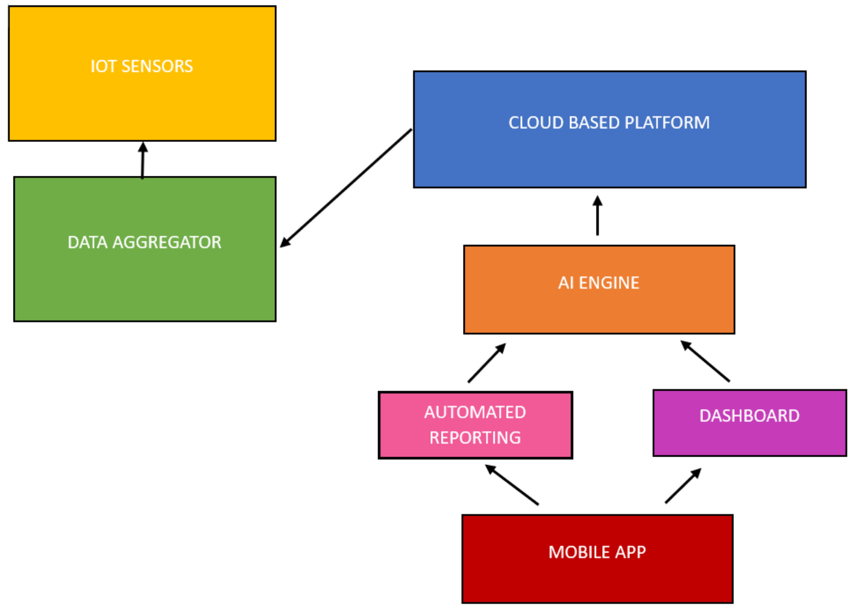
Mobile Access: A mobile application allows users to monitor energy usage remotely, receive alerts, and make adjustments on the go, ensuring constant oversight.

Automated Compliance Reporting: The system generates reports automatically, ensuring compliance with local and international energy regulations.

Scalable Cloud-Based Infrastructure: Hosted on a cloud platform, the system ensures data security, scalability, and ease of access, with minimal on-site IT infrastructure needed.

Energy Optimization Algorithms: Advanced AI algorithms analyze energy usage patterns and suggest optimization strategies, such as load shifting, peak demand management, and alternative energy sourcing.

9.2. Schematic Diagram



9.3. User flow

System Setup:

IoT sensors are installed across the manufacturing facility, and the Data Aggregator is configured to collect and send data to the cloud. The user selects the modules required for their business, such as energy monitoring, predictive maintenance, and compliance reporting.

Real-Time Monitoring:

IoT sensors begin collecting real-time data, which is sent to the cloud platform. Users log in to the dashboard, where they can view live energy consumption metrics, alerts, and notifications.

AI-Driven Insights:

The AI engine processes data and sends alerts if potential equipment failures are detected. The system suggests actionable strategies for reducing energy consumption based on usage patterns.

Mobile Access:

Users can access the mobile app to monitor energy usage remotely, receive alerts, and make real-time adjustments. Critical alerts, such as predictive maintenance warnings, are sent via push notifications.

Automated Reporting:

The system automatically generates and sends energy compliance reports based on the latest regulations. Users receive regular reports summarizing energy usage, cost savings, and system performance.

10. Product Details

10.1. How does it work

Installation: Sensors are installed on machinery. The IoT hub connects to these sensors and transmits data to the cloud.

Data Processing: The AI engine processes the incoming data to detect patterns and identify potential energy inefficiencies.

Optimization: The system suggests specific actions, like adjusting machine settings or scheduling operations during off-peak hours.

User Interaction: The user accesses the system via a web or mobile app, where they can view energy usage reports, receive alerts, and implement optimization suggestions.

10.2. Data source

Real-time energy consumption data from sensors.

Historical energy usage data for trend analysis.

External data like energy prices and weather conditions for contextual optimization.

10.3. Algorithm, Software, Technologies

AI Algorithms: Time-series analysis, anomaly detection, optimization algorithms.

Frameworks: TensorFlow, Keras for AI modeling.

Software: Python for data processing, AWS for cloud services, MQTT for IoT communication.

10.4. Team requirements

Data Scientists: To develop and refine the AI models.

IoT Engineers: To design and implement the sensor network.

Software Developers: To build the user interface and integrate the system.

Energy Experts: To validate and refine optimization suggestions.

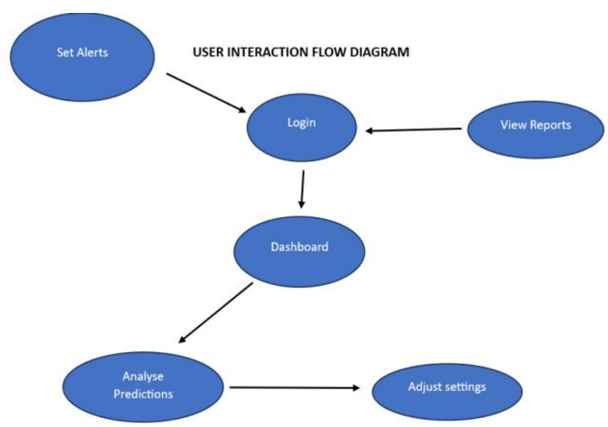
10.5. Cost

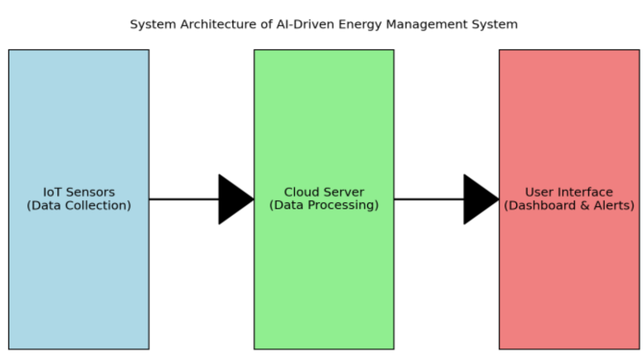
Development Costs: Moderate, with initial investment in AI and IoT development.

Ongoing Costs: Cloud hosting, maintenance, customer support.

Pricing Strategy: Affordable subscription pricing to appeal to small businesses.

11. Product Diagram





12. Code implementation

12.1. Data simulation

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from datetime import datetime, timedelta

# Simulate data for 5 machines over a period of 30 days
np.random.seed(42)
date_range = pd.date_range(start="2024-01-01", end="2024-01-30", freq="H")
machines = ['Machine_1', 'Machine_2', 'Machine_3', 'Machine_4', 'Machine_5']

data = {
    'timestamp': np.tile(date_range, len(machines)),
    'machine': np.repeat(machines, len(date_range)),
    'energy_consumption': np.random.normal(loc=50, scale=10, size=len(date_range) * len(machines))
}

df = pd.DataFrame(data)

# Simulate some anomalies (e.g., spikes in energy consumption)
anomalies = np.random.choice(df.index, size=20, replace=False)
df.loc[anomalies, 'energy_consumption'] *= 1.5

print(df.head())
```

12.2. Data analysis and visualization

```
# Plot energy consumption for all machines
plt.figure(figsize=(12, 6))
for machine in machines:
    machine_data = df[df['machine'] == machine]
    plt.plot(machine_data['timestamp'], machine_data['energy_consumption'], label=machine)

plt.xlabel('Timestamp')
plt.ylabel('Energy Consumption (kWh)')
plt.title('Energy Consumption Over Time')
plt.legend()
plt.show()
```

12.3. Predictive maintenance

```python
from sklearn.model_selection import train_test_split
from sklearn.ensemble import RandomForestClassifier
from sklearn.metrics import classification_report

# Create a binary label for machine failure
df['failure'] = np.where(df['energy_consumption'] > 75, 1, 0)

# Feature Engineering
df['hour'] = df['timestamp'].dt.hour
df['day'] = df['timestamp'].dt.day

# Prepare the data for modeling
X = df[['energy_consumption', 'hour', 'day']]
y = df['failure']

X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42)

# Train a Random Forest Classifier
model = RandomForestClassifier(n_estimators=100, random_state=42)
model.fit(X_train, y_train)

# Predict and evaluate
y_pred = model.predict(X_test)
print(classification_report(y_test, y_pred))
```

12.4. Visualization

```python
import streamlit as st

st.title("AI-Driven Energy Management Dashboard")

# Display Energy Consumption Plot
st.subheader("Energy Consumption Over Time")
for machine in machines:
    machine_data = df[df['machine'] == machine]
    st.line_chart(machine_data.set_index('timestamp')['energy_consumption'])

# Display Optimization Suggestions
st.subheader("Optimization Suggestions")
st.table(df[['timestamp', 'machine', 'energy_consumption', 'optimization_suggestion']].head(10))

# Predictive Maintenance Insights
st.subheader("Predictive Maintenance")
st.write("Machine Failure Predictions based on Energy Consumption:")
st.write(classification_report(y_test, y_pred))
```

13. Conclusion

The AI-Driven Energy Management System for small and medium-sized manufacturing units represents a significant advancement in how SMEs can manage their energy consumption. By integrating real-time IoT monitoring, AI-driven predictive maintenance, and energy optimization algorithms, this system offers a comprehensive solution tailored to the unique needs of smaller businesses.

The modular design ensures that the system is both flexible and cost-effective, allowing businesses to adopt only the functionalities they need. The cloud-based infrastructure and user-friendly dashboard make the system accessible to non-experts, while the predictive analytics and automated compliance reporting provide substantial operational benefits, such as reduced downtime and ensured regulatory compliance.

The small-scale code implementation validates the core functionalities, demonstrating how simulated energy data can be used to predict equipment failures and optimize energy usage. These initial results indicate that the system has the potential to deliver real-world value by lowering energy costs, minimizing equipment failures, and helping SMEs meet sustainability goals.

In conclusion, the AI-Driven Energy Management System is not only a technologically viable product but also a strategically important tool that aligns with the growing need for efficiency and sustainability in the manufacturing sector. Its development and deployment could have a profound impact on the operational efficiency and cost-effectiveness of SMEs, providing them with a competitive edge in an increasingly challenging economic environment.

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