Real-Time Data Collection to Improve Energy Efficiency in Food Manufacturing

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Abstract: *The demand for energy is on the rise which is caused by a combination of global economic progress and population growth. The food sector is a significant consumer of energy at each stage of the supply chain, i.e. from farm to fork. Hence, improving efficiency and recognizing potentials for energy conservation has become essential in order to address the challenges faced by the food sector. However, most food manufacturing businesses, especially small and medium scale enterprise, have limited awareness of significant potentials offered through the recent technological advancements in real-time energy monitoring. In this context, the concept of 'Internet of Things' (IoT) has investigated to increase the visibility, transparency and awareness of various resource usage, thanks to the availability of inexpensive and smart sensing devices. This paper presents a case study of a beverage factory where the implementation of IoT-powered sensors and smart meters is based on the embodied product energy (EPE) modelling. This arrangement enabled the collection of real-time data on energy consumption within a food production system to support more informed engineering and operational decisions, leading to an improved energy monitoring and management, as well as substantial cost savings.*

Keywords: Food Supply Chain; Food Manufacturing; Internet of Things; Energy efficiency;

1. INTRODUCTION

Energy is one of the vital resources in the food manufacturing industry and is also a significant user of it. The availability of uninterrupted energy supply in future is a reason for concern due to the depleting fossil fuel resources and increasing global population. As per the 2012 UNESCO report, the food production and supply chain were responsible for 30% of the total global energy consumption (UN Water, 2015) and this was mainly in four food production related activities: agriculture, transportation, processing and food handling as shown in Figure 1. The threat of energy shortages and higher energy costs are already looming over the food sector, and they need to address it on an urgent basis.

The food manufacturing industry is exploring various ways to improve its energy efficiency to reduce energy costs, carbon emissions and negative environmental impacts. Some of the options to reduce energy consumption are: a reduction in the energy-intensive activities without affecting the profitability of a manufacturer, better energy management and energy recovery (Woolley et al., 2018). Energy management systems (EMS) is being widely implemented (Schulze et al., 2016) in the food manufacturing sector to achieve and sustain energy usage improvements. EMS is complicated with various parameters such as energy production, energy import/export, energy storage, energy conversion, energy transmission and energy consumption and the situation could be further complicated by other uncertain parameters (Cai et al., 2009). Hence, to improve the energy efficiency, there is a need for a system which provides a detailed real-time energy usage breakdown of their production facilities. The IoT-based energy sensors and meters can give visibility and reliability on the efficiency and productivity of energy consumption. It provides critical information to management on energy consumption levels of various production facilities, thereby allowing them to make better decisions in real-time to reduce overall energy usage.

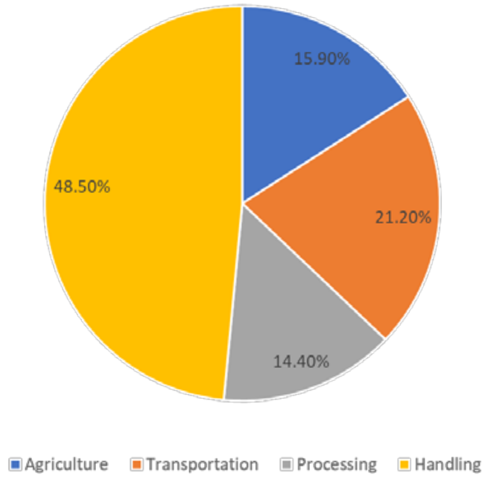


Figure 1 Energy in Food Production (Lillie, 2015)

The initial sections of this paper present a brief review of technologies currently adopted in food manufacturing plants to optimise the energy usage as well as a framework for measuring the embodied food product energy based on Seow and Rahimifard (2011). The latter sections present a case study on how a food manufacturing facility implemented smart energy metering linked to an IoT system based on EPE model to reduce its annual energy consumption and thereby increase its profit margins. The industrial case study also demonstrates how such a smart energy system could support long-term decisions for the elimination of energy wastages within the factory.

2. LITERATURE REVIEW

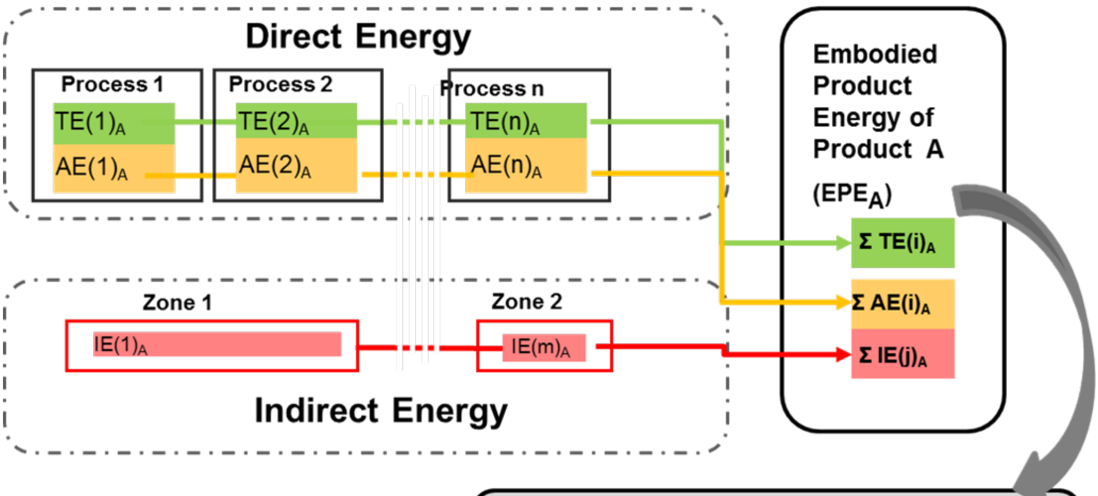
The international standard ISO 50001 Energy Management Systems published in 2011 supports organisations in achieving continual improvement of energy performance including using energy more efficiently through implementing an energy management system (Jovanovic & Filipovic, 2016). It establishes the structure and discipline to develop technical and management approaches that massively cut downs the energy costs and greenhouse gas (GHG) emissions (Lee & Cheng, 2016) —and maximises savings over time (OECD, 2015).

However, energy efficient technologies and equipments are not currently pursued in the industry due to limited short-term economic benefits and very long payback time (Chiaroni et al., 2016). Therefore, Backlund et al. (2012) stated that rather than investing in costly technologies to improve energy performances, it is worth to finance the inexpensive energy metering and monitoring supported by energy efficient management practices. Tanaka (2011) suggested various activities that can be taken on by industry for better energy management, such as: sustaining, restoring and reorganising the equipment to minimise energy loss; retrofitting, substituting and disposing out-dated equipment, process lines with novel technologies and better insulation to reduce heat loss and waste energy, reutilising wasted heat and energy; better process control for improving energy, materials efficiency and process productivity; and restructuring processes by adopting new production concepts. In order to make any EMS work, industry needs to measure their energy consumptions in detail and then only they will be able to manage their energy bills (Allen-Bradley - Rockwell Automation, 2017). But then most of the food manufacturers monitor their energy consumption through monthly energy bills (Carbon Trust, 2012) and to have data on energy consumption for each department, and at the machine level is a far-fetched story (Shrouf & Miragliotta, 2015). Therefore, reducing energy consumption becomes a complicated process for decision-makers in this industry. This issue can be successfully addressed by having access to real-time data on energy consumption (Shrouf et al., 2014). It is an important tool which allows the decision makers to extract meaningful information for successful energy management (Efficiency New Brunswick, 2010).

Nowadays, a novel concept of the Internet of Things (IoT), which enables physical objects to communicate and exchange data with each other using low-cost sensors, software and other electronics has taken centre stage (Li et al., 2015). IoT technology is revolutionising the way organisations are collecting and analysing the data in order to address the operational inefficiencies in real-time (Vera-Baquero et al., 2016). It has already created better connectivity through visible and transparent data, business collaborations, operational changes and created value by providing new services and applications (Li et al., 2015). In the food supply chain, IoT is being considered as a way to improve operational performance, safety and profits by monitoring the quality, tracking food logistics, predictive maintenance and warehouse management to avoid spoilage of food (Pang et al., 2015). IoT is swiftly spreading its wing across various operations within food manufacturing, and energy is one of the many interesting application domains where it can have major impact and influence. IoT provides a real-time solution for monitoring energy consumption to decision-makers with key data of the machines, the production lines and even at the factory level (Shrouf & Miragliotta, 2015).

3. EMBODIED FOOD PRODUCT ENERGY FRAMEWORK

Most of the food manufacturing plants are usually aware of their energy usage through their monthly or quarterly energy bills. However, they are not aware of the detailed energy usage at the machine or departmental level. It is, therefore, necessary for food manufacturers to understand the energy patterns and key data on energy usage at the process level in order to reduce their overall energy consumption. In this context, the food manufacturers should have access to a smart system which can measure the energy used by various manufacturing processes for a given food product. Seow and Rahimifard (2011) defined a framework for modelling embodied product energy, as shown in Figure 2. In this framework, the Embodied Product Energy (EPE) consists of two energy groups, i.e. Direct energy (DE) and Indirect energy (IE).



$$EPE_A = \sum_{i=1}^{n} DE(i)_A + \sum_{j=1}^{m} IEzone(j)_A$$

Figure 2 Embodied Product Energy Framework (Seow & Rahimifard, 2011)

The DE is the energy used by various processes to manufacture a food product (e.g. washing, cooking, packing, inspection etc.), whereas the IE is the energy utilised by activities to sustain the environment in which the production processes are carried out within a food factory (e.g. lighting, heating, utilities). The DE can be further classified as: Theoretical energy (TE) and Auxiliary energy (AE). TE is defined as the minimum energy needed to carry out a certain process (e.g. energy for washing vegetables), whereas AE is the energy required for supporting activities which are non-productive (e.g. machine start-up or on standby). The sum of the DE (i.e. TE + AE) together with IE for all the activities within a food production system represents the total embodied energy of the food product. The smart energy monitoring system, therefore, should be able to clearly identify all kinds of energy mentioned above in order to be energy efficient.

Adopting such smart energy monitoring and modelling in food production systems would result in detail information on the energy usage by various processes and could identify energy hotspots within a factory. Those processes which are energy intensive can be substituted with the less energy-intensive process to improve the energy efficiency. In addition, such breakdown of energy usage data at process level can be used to investigate the effect of other production parameters such as the number of trial runs, batch size, production schedules, etc., and can provide detail understanding of which production parameters combination yield best energy efficiency results without affecting production outputs.

4. IOT ARCHITECTURAL LAYERS

In order to be energy aware through EPE model, food manufacturers can adopt an IoT based approach of installing smart energy meters at various energy hotspots coupled with software to support the task team (decision-makers) to monitor the energy consumption patterns and trends. It will, in turn, help decision makers to devise solutions to reduce the overall energy consumption and this could be achieved by adopting a simple four-layered architecture based on Jagtap & Rahimifard (2017) and Li et al. (2015), which is described as follows:

- Sensing layer - The bottom layer also called as Sensing layer consists of smart energy meters which captures the power consumption data that are required by decision-makers for monitoring and benchmarking energy patterns.

- Networking Layer - The communication between various things such as meters, users, and server are carried out via a wireless network, and hence this layer is called as Networking layer. This layer provides a seamless transfer of data between smart meters and the host server via wireless communications (Internet, Bluetooth) or wired communication.

- Service Layer - The real-time data acquired from meters are stored on the server and using software are continuously analysed for energy patterns and trends and therefore is termed as Service or data layer. This layer is the most important layer as it contains all the logic to store and process the data in order to make the application work.

- Application Layer - The final and the topmost layer is termed as an Application layer because it serves the users with detailed analysis of energy consumption in the form of dashboards, sends alerts and generates reports. It makes use of the control buttons on the user interface application to communicate with backend software to process the data.

5. CASE STUDY

5.1. Company Profile & Business Overview for Energy Efficiency

The case company is based in India. It is one of the largest beverage manufacturing plants and operates three bottle filling lines in a 24-hr shift. Due to the rising raw material and energy prices which led to higher manufacturing costs, the company's focus was on reducing the energy bills. Due to cut-throat competition with other beverage manufacturing companies and to be a sustainable business for an extended period, it was evident that the company must take initiatives in reducing the manufacturing costs to increase its profitability. Since influencing the raw material cost was not within their control, the only possible solution, in order to remain sustainable, was to implement the IoT-based Energy Management System to improve energy efficiency.

5.2. IoT-Based Energy Management System Development and Implementation

Top management was committed towards the adoption and implementation of the IoT-based EMS. A task team was formed to encourage employees to get involved and understand the new system. The team consisted of employees from various departments and included a mix of senior and junior management members. Each member was responsible for the energy performance of their respective department.

Energy sources were identified, and the historical energy trends and patterns and the current demands were evaluated. Machines, equipment, people, processes and the departments which contributed to the significant amount of energy use were recognised. In order to improve the energy efficiency of the manufacturing facility, the conditions which attributed to the excessive amount of energy consumption were prioritised, and other energy saving opportunities were also zeroed in. The initial energy consumption analysis supported the decision-makers with setting up an energy baseline and target for each department.

Energy smart meters and sensors installed in each area and on some machines to measure the energy consumption allowed the daily real-time monitoring of energy usage and efficiency. Figure 3 shows how each process and power-hungry equipment such as boilers and cooling towers mounted with smart energy meters were deployed to measure their energy consumption. The energy data collected by these smart meters are transmitted wirelessly to a central database where they are stored and analysed to extract meaningful information. The extracted meaningful information in the form of user-friendly dashboards is then presented to all the energy concerned employees.

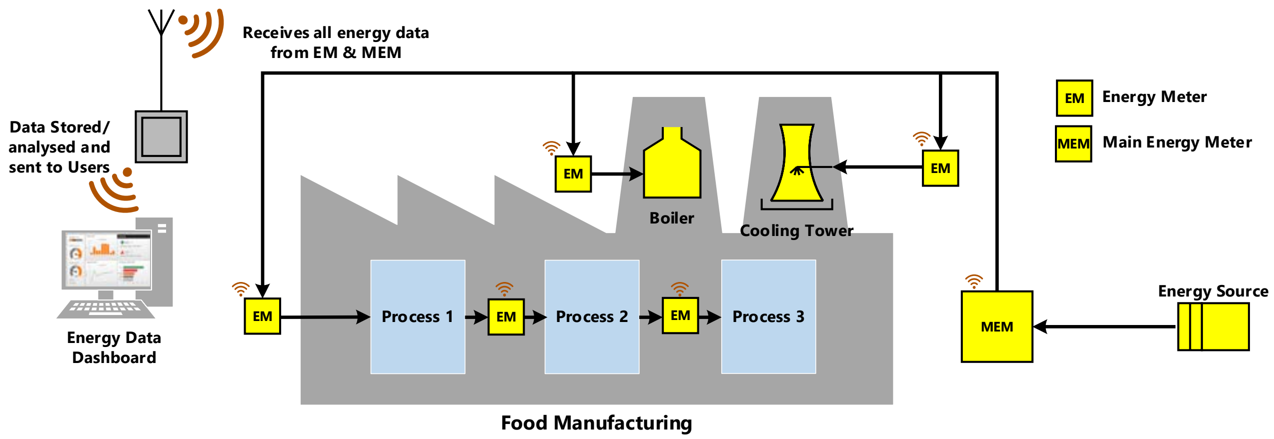


Figure 3. Energy Monitoring System

The energy task team collected the energy data based on EPE model for a period of 10 months starting from April 2017 as shown in Figure 4. The finished product row shows, the quantity of beverages manufactured, each month in kilo-litres (m^3). Based on the historical production data from the best performing site within the group the average expected electricity consumption data was derived. The average expected electricity consumption data was calculated from the number of liters of finished beverages produced per kWh of electricity consumed. The target electricity consumption was decided by the task team and was always kept below the expected electricity consumption on an average by 1400 kWh in order to compensate for the unpredicted increase in orders or energy consuming refurbishments. The actual electricity consumption data is the data recorded by the newly installed smart energy meters. The Savings row shows how much electricity was saved or lost for each month. For the months of April 2017 to July 2017, the factory overused electricity and there were no savings which are highlighted in red. During this four-month period the energy task team monitored and analysed the energy consumption of various machines and equipments and narrowed down which energy saving projects to undertake. The team identified five energy saving projects which were implemented by the end of July 2017. These initiatives helped them reduce their energy consumption, and the benefits can be seen in green for the months of August 2017 to January 2018.

5.3. Energy Saving Projects

The IoT-based energy monitoring system gave the task team access to significant amounts of energy data with structure. The energy task team undertook five projects after monitoring their energy consumption for the first four months as shown in Table 1. The team proposed each project to senior management and presented them a payback period for each investment. All the projects were successfully delivered due to the structured energy data on demand, following the EPE framework using IoT-based monitoring system, greater visibility and measurement of projects, an increased stakeholder engagement throughout the company and reduction of risk from carbon compliance.

Electricity Consumption Data											
Month		**Apr-17**	**May-17**	**Jun-17**	**Jul-17**	**Aug-17**	**Sep-17**	**Oct-17**	**Nov-17**	**Dec-17**	**Jan-18**
Finished product in Litres	kL/month	129034	117938	114715	127886	121232	110427	124080	94089	126092	119330
Expected Electricity Consumption	kWh/month	149966	138313	134929	148760	141772	130426	144763	113268	146876	139775
Target Electricity Consumption	kWh/month	148456	136921	133570	147263	140345	129112	143306	112126	145398	138368
Actual Electricity consumption	kWh/month	189399	193937	199101	210850	120750	96510	103524	82843	110501	102777
Savings	kWh/month	-39433	-55624	-64172	-62090	21022	33916	41239	30425	36375	36998

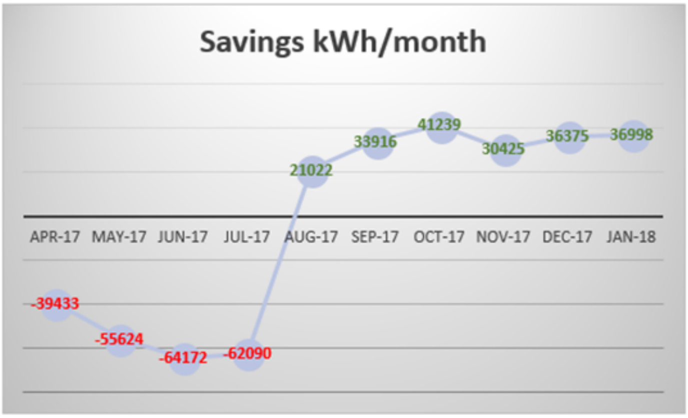


Figure 4 Electricity Consumption Data & Electricity Savings

Table 1. Energy Saving Projects

Sr. No.	Energy Saving Projects	Per annum savings kWh	Annual savings in USD ($)	Initial cost in USD ($)	Payback period (months)
1	Replacing 10 TPH boiler with 6 TPH boiler	-	74,374	85,825	13.85
2	To replace 36 watts white tube lights with 16 watts Light Emitting Diode (LED) tube lights	661,305	85,667	30,054	4.48
3	To install Variable Frequency Drive (VFD) in beverage filling pumps	17,184	2,090	1,431	8.22
4	Replacing fluid coupling motor with efficient VFD motor	8,592	1,044	2,175	24.65
5	Converting chiller plant to humidification plant	120,000	14,316	42,950	35.29

6. CONCLUSION AND FURTHER WORK

This paper addresses how the EPE framework supported with the novel concept of IoT can be utilised to monitor energy in real-time and thereby improve the energy efficiency of the food manufacturing unit. It allowed a high level of energy awareness among the decision makers enabling them to make better decisions related to energy usage. The detailed categorisation of EPE data allowed management to understand their energy consumption patterns. The theory was proved through a case study of the beverage factory which showed how it was able to achieve $172,281 of annual energy savings and save 807,081 kWh/annum of electricity. It further demonstrated how IoT-based energy monitoring solutions are vital for the food sector and need to be included in the factory's energy management initiatives. The ability to understand the production-related decisions that are resulting in higher consumption of energy will be a topic of further study.

ACKNOWLEDGEMENTS

This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) Centre for Innovative Manufacturing in Food [Reference: EP/K030957/1].

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