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# Real-time Linked Open Data for Life Cycle Inventory

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**Abstract.** The quality of data used for the Life Cycle Assessment (LCA) is of prime importance as they influence the outcomes of the impact assessments. Most of the LCI data has validity periods as the data gets outdated due to introduction of new technology and process. In order to replace outdated data with most recent value we have developed a device called EnBoX (Energy Baseline of X) for real-time power measurement and which would be used for generating Linked Open Data. In this paper a semantic web based Linked Open Data architecture is developed to update the sensed data into an LCI database. A case study is presented in this paper by updating an existing data base of injection moulding process with an Open LCI data base using the proposed method. The LCI data is open and could potentially eliminate the data validity issues arising out of conventional LCI data gathered over time. The work presented in this paper would be useful to manage sustainability performance of products/processes in an accurate manner.

**Keywords:** Life cycle assessment, Open data, Linked data, Life Cycle Inventory.

## 1 Introduction

Life Cycle Assessment (LCA) is an approach to quantify the environmental impacts associated with all the stages of the product life. The LCA needs a long list of input and output impacts data at the unit process level and that is usually available in a database called Life Cycle Inventory (LCI) [1]. The existing LCI databases are developed by collecting the data manually at various stages by different people and consolidated by the LCI service providers. But the challenges of the existing data collection techniques are poor quality and accuracy of the data. To match with current data quality standards, specified in the ISO 14000 series standards, various service providers within the LCA community have developed different methodologies to improve the quality of Life Cycle Inventory (LCI) data and few researchers have used modern technologies like ICT (Information communication and Technologies) and IoT (Internet of Things) [7] as a tool for collection and assessment of data. So, in this paper we are proposing a real time open LCI data updated in the database using the concepts of linked data and semantic

web [2]. More state of the art technologies related to the data collection in LCI is discussed in the following sections.

## **2 Dynamic LCI and semantic based Life Cycle Impact Assessment**

Usually LCA is carried out after collecting all related data. In contrast to the existing techniques, Remo et al., [3] presented a method to perform a web-based dynamic LCI and LCIA for manufacturing processes by implementing a system based on combining Labview and GaBi software, as well as MTConnect® standard for data collection. Similar to [3] Brandon et al., [4] have used a standardized LCA catalog that can express the semantic content of a data resource. By using this catalog, a user can generate LCI data by querying the requirement for the LCA. The query responses can be enriched through integration with linked data services that are in development or already exist.

Most of the existing LCI has three different flows material flow, water flow and energy flow. To implement sustainable manufacturing [5] in industries have to closely monitor the energy flow. So, we have limited our scope of our study to energy related flows in the LCI data.

### **2.1 IoT based device for energy monitoring**

Few researchers [6-8] have developed the IoT based devices for monitoring the energy consumption and used the measured data for various downstream analysis. In home automation systems, Putta and Balamurugan [6] used IoT approach for continuous monitoring and control of the appliances far from their home using connected devices thus achieving Energy Efficiency (EE). Lidia et al., [7] presented an open IoT infrastructure that provides real-time monitoring in multiple school buildings. Shee et al., [8] introduced an IoT enabled software application for real-time monitoring of EE on manufacturing shop floors.

But all these data are static in nature and after over a period, the data may become outdated/invalid. So, we need a real-time open LCI data where the data values are updated in the database as the manufacturing facility is in use. In order to solve the problem stated above we propose a systematic approach to develop a real-time open LCI in the following section.

## **3 Methodology**

LCI development is creating an inventory of flows from and to the environment during product/process development, among all the flows our focus is on the energy flows. So here we present the development of an energy measurement device, its ability to push sensed data into the cloud and the overall architecture of the semantic annotation system that enriches the data from monitoring device for consumption by an LCA system. Fig.

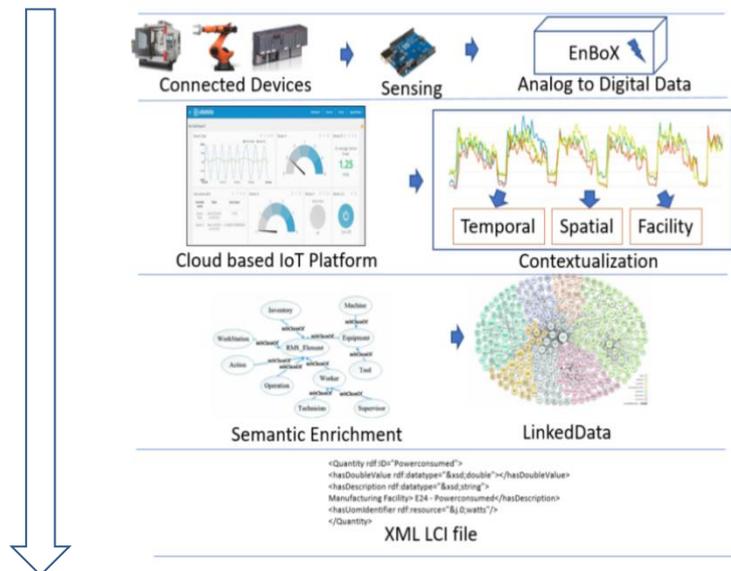
1 demonstrates the proposed framework for integrating the sensed data with the semantic Web to develop the open LCI database and detailed description of the architecture is given in the following sections.

### 3.1 Overall architecture for Open LCI data preparation

In this frame work the primary stage is sensing the data from the device which we need to monitor for energy consumption. These connected devices can be any manufacturing facility that we use during the product development stage or in the product use stage. If we consider a bottle produced with polypropylene material by using the injection moulding process, the sensing device can be connected to the injection moulding machine to monitor the energy consumption during the production of the bottle in the shop floor.

#### Sensing devices

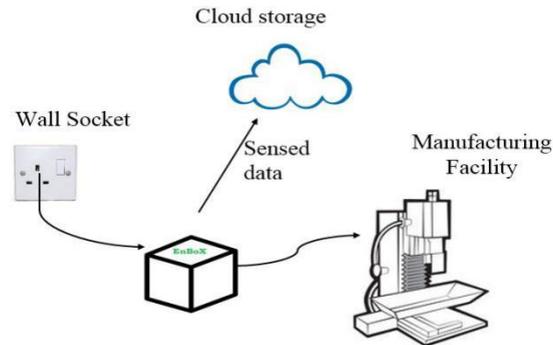
During development of an LCI data sets we need to monitor different flows associated with the unit process like material input, energy consumption and emissions to the air, water and land. To monitor each flow we insist on different sensors, for example to measure the emission of particulate matter 2.5 to the environment we use light scattering sensors. But in this work, to monitor the energy consumption, we have used a non-invasive current sensor to calculate the total electric energy consumption by using a device known as EnBoX.



**Fig. 1** Overall architecture of Open LCI data

### Energy measuring device (EnBoX)

An IoT based device like [7] has been used to measure the energy consumption and we named it as EnBoX where X can be any equipment which can be used in manufacturing of the product. The Fig. 2 shows the overall system architecture.



**Fig. 2.** Architecture of EnBoX

EnBoX consist of an Arduino, a non-invasive current sensor, a rectifier circuit and a Wi-Fi module. Arduino is programed to calculate the power by multiplying the voltage with the current sensor data. The Wi-Fi module will help us to push the derived sensor data in the IoT based cloud platform known as Ubidots.

### Cloud Based IOT Platform

IOT based cloud platform is designed to store and analyze different data collected. In this work we used Ubidots as a cloud storage platform to store the real-time data that is sensed by the EnBoX.

### Contextualization

The analog data generated from the EnBoX is semantically enriched in the cloud before it is published. Before content curation, the data are contextualized based on location, time and the manufacturing facility for which power is measured, so that anyone who queries data for a certain region/location or the manufacturing facility/equipment can get access to the data very easily.

### Semantic enrichment and linked data preparation

The idea behind the Linked data is to increase the usefulness of data as it is interlinked with large amount of other data. On one hand, the connection enables qualitative annotations to promote interoperability, and thus avoid creating repetitive data with the help of the ontology prepared for an LCI input and output flows. The data already published on the semantic Web can be widely used by communities for the LCA. During the

impact assessment using the open LCI data, the sensed data is updated based on the semantic web.

The enriched data can be probed using a RESTful server connection to the cloud and the data is presented to the user in an XML file unlike the SPINE and SPOLD formats used in conventional LCI data. One can perform LCIA with the data obtained from the Linked data.

### 3.2 Case study

A representative LCI data from the NREL database is considered and its important flows, object and data properties (category, flow type, unit measured and amount) are used to prepare the case study ontology. The ontology created for both input and output flows are graphically represented in Fig. 3. Then the prepared ontology is presented as an XML LCI file. As and when the EnBoX is connected to equipment to monitor the energy consumption, the real-time values will be updated in the Open LCI database.

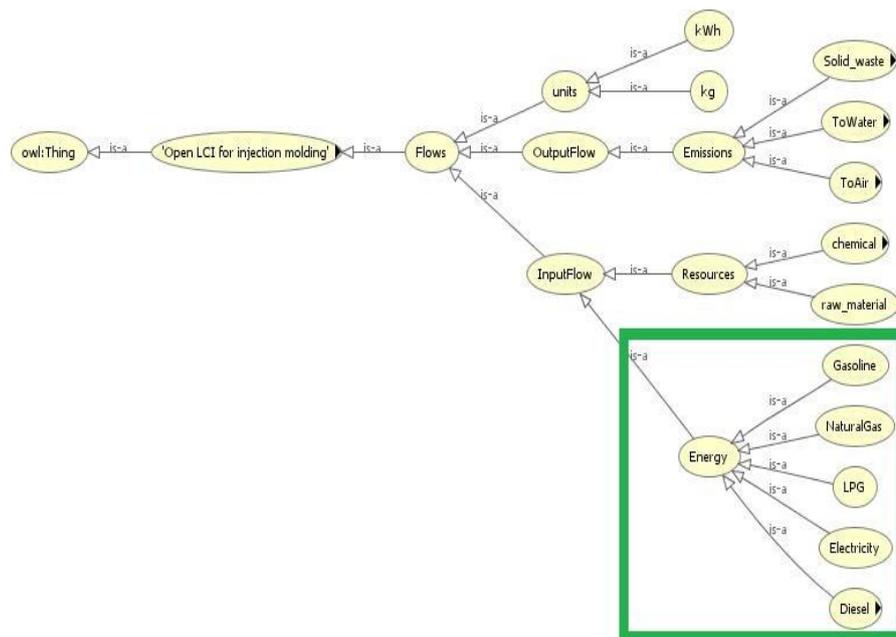


Fig. 3 Ontology for the LCI data

As mentioned earlier, we are focusing only on the energy flows in the unit process, which is highlighted in the Figure 3. Among the five-energy source EnBoX will measure the electricity consumption in real-time and represent the value in LCI database using an XML Schema for LCI data. Then the most recent value stored in the cloud platform can be updated to an LCI database periodically or when the user demands for the LCI data.

## 4 Conclusions

With the help of industry 4.0 tools and modern technologies like linked data and semantic web, a real-time open LCI data collection system, which helps to have pinpoint assessment of the product/process throughout its life cycle is proposed. This system will reduce the cost incurred in the LCA process. However, this poses challenges in terms of sharing proprietary data over to large audience, cyber-security and repetitive sensed data for similar products and processes. Crowd sourcing also brings challenges in terms of peer-reviewing the LCI data which must be addressed. The future work is to develop connections to OpenLCA to perform impact assessment using the XML LCI Schema.

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