Evaluating Sustainability, Environment Assessment and Toxic Emissions in Life Cycle Stages of Printed Antenna

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Abstract

In this work cradle to grave life cycle assessment of printed electronics resources have been presented. An attempt has been made to investigate and evaluate the life cycle assessment and environmental impacts of printed electronics resources such as polymer substrate-printed RFID antenna. Life cycle inventory analysis for these resources has been carried out to quantify total systems' inputs and outputs that are relevant to the environmental impacts especially emissions to air, fresh water, industrial soil and sea water. The results show that printed electronics materials are considerably more environment friendly than materials needed for PCB electronics. We have obtained the mass of emissions in each life cycle stages which verify that technology wise printed antenna causes less harmful and hazardous impacts to the environment.

1. INTRODUCTION

The present research scenario towards the embedded system shows that analysis of life-cycle has not been a core focus for embedded systems researchers, such topics typically being left to the expertise of other communities. To maximize a researcher's contribution to efficient products, manufacturing industry processes and services, there is a strong need to increase life-cycle awareness among embedded systems researchers, so that the next generation of engineers will be better able to integrate the goal of a sustainable life-cycle.

Market analysis and research reports estimate that printed and organic electronics will become a huge, several hundred billion dollar business in the near future [1]. Motivated by the evidence of increasing demand of printed electronics in the near future, our aim is to develop an understanding of the life cycle assessment of printed electronics materials and to analyze the environmental impacts in terms of emissions to air, fresh water, sea water and industrial soil. In this paper, we have attempted to examine the following research questions. What are the quantitative emissions in each life cycle stage of printed RFID antenna? How severe are the impacts of...
environmental emissions with the case of using PCB technology? What are the amounts of toxic emissions in each technology?

The rapid progress in telecommunications deals with a great variety of communications systems like cellular communications, global positioning, and satellite communications. Each of these systems operates at several frequency bands employing a number of small to large antennas depending upon the choices of applications. Moreover printed antenna offers an excellent performance in wide applications of wireless communication. The recent trends give evidence that productions of antenna for different applications are growing rapidly. Hence we chose printed antenna as a case study. At the outset, it is useful to explain what we mean by life cycle assessment and printing methodologies in context with this research [2]-[9]. We have considered inkjet printing methodology in production of RFID antenna and have developed a model using life cycle assessment (LCA) software. The major compositional components of printed electronics materials are studied with reference to emissions into the environment. The goal of this study is to quantify the environmental emissions in different life cycle stages such as raw materials preparation, production process and end of life cycle of the printed antenna. In order to facilitate analysis, the environmental evaluation of the printed technology has been carried out and compared with the conventional PCB technology. The key parameters for comparison include the energy usage, hazardous emissions from raw materials preparation, production process and end-of-life of the printed antenna.

Substantial research has been conducted on several key areas related to the life cycle assessment and environmental impacts of printed electronics materials. Some of them are printed electronics manufacturing line with sensor platform application, LCA of carbon nanofibers and inkjet print cartridges [10]-[13]. The academic literature has not focused on quantitative environmental emissions in air, fresh water due to production of antenna in printed and PCB technologies. Therefore here our work is to quantify the total environmental emissions due to production of printed RFID antenna in all three life cycle stages of raw materials preparation, production processing and end of life cycle and also to compare them with PCB technology. A model has been realized in both the technologies using Gabi 4.0 environmental assessment tool to obtain the results in terms of input resources utilization and environmental emissions. With analysis of fabricating one million printed RFID antennas and PCB antennas, our results show that resource consumption in PCB technology is considerably larger than that of the printed electronics technology. We have also investigated the life cycle assessment and environmental impacts of printed RFID antennas in all three life cycle stages.

Our paper is structured as follows. The next two sections provide the theoretical underpinnings of our assumptions in procedural flow diagram and process interpretation. Section 4 describes our research analysis in each life cycle stages. Comparative Analysis and toxic emissions are described in sections 5 and 6 respectively and conclusion and future works are presented in section 7.

2. PROCEDURAL FLOW DIAGRAM

The procedural flow diagram shown in Fig. 1, describes the start to end flow in the process of life cycle assessment of printed antenna. A plan is the basis for connecting different processes and thereby, modeling the steps
of printed electronics life cycle. It is a representation of the system boundaries. A flow is the base unit in life cycle assessment software. It describes the material or energy flow between two processes. Processes are connected to one another by product flows. The process instance is the local process settings after the plan is completed with the set of processes and corresponding flows. The supporting database comprises of inputs and outputs for the specified process. The inputs are in the category of renewable resources, non renewable resources, minerals, waste for recovery, thermal energy. In similar way, output represents environmental impacts such as inorganic/organic emissions to fresh water/air/sea water, heavy metals to air, and hydrocarbons to fresh water and so on. Balances are used to view the results of the proposed model. They can be evaluated in a variety of different ways. Balances can be calculated based on single or multiple processes and plans.

3. PROCESS INTERPRETATION

A process is defined by its input and output flows. The plan comprises of different manufacturing processes. Usually manufacturing process of printed antenna requires two major substances. These are the input parameters for LCA. During the process interpretation one has to consider quantity, amount and particular unit of the materials. The output results of LCA depend on how input parameters and their magnitudes are considered during the process. The real composition and magnitudes of the printed RFID antenna can be obtained after life cycle inventory analysis (LCIA). Table 1 and Table 2 respectively show the process interpretation for manufacturing printed RFID antenna and traditional PCB antenna. In both the technologies, the total masses of materials utilized are different. The masses of materials are chosen as per the knowledge of fabrication of antenna [14]-[21] in both the technologies. For the production of 1 million printed RFID antennas, it requires 800kg of PVC sheet and 208kg of copper mix.

4. LIFE CYCLE STAGES

The main objective here is to quantify the environmental emissions in different life cycle stages such as raw materials preparation, production process and end of life cycle of the printed and PCB antennas. Beginning from Raw materials preparation stage, we have estimated consumption of raw materials in fabricating one million of printed and PCB antennas. For printed RFID antenna polyvinyl chloride sheets and copper mix are usually employed. The PCB antenna comprises of raw materials such as active and passive electronic components, plastics and copper strips. The modeling plan for printed and PCB antenna are shown in Fig. 2 and Fig. 3 respectively. The rectangles illustrate the processes and flows give an idea of amount of materials to construct the antenna.

Here, we have attempted to visualize the environmental emissions for the plans illustrated in Fig. 2 and Fig.3. The total environmental emissions in the raw material preparation stage are shown in Fig. 4 and Fig.5 respectively. The emissions to the air dominate clearly in both the technologies. The production process of printed antenna solely employs inkjet printing methodology that consumes conductive ink. The conductive ink is an alloy of carbon and silver deposited on the substrate. The production process of PCB antenna comprises of power grid mix, capacitor, filter, solder paste, resistors, transistors, silicon mix, ICs, printing wiring board and assembly line. The third stage is end of life. Here we have considered incineration and land filling techniques of printed antennas. In both the techniques we have computed the emissions to air, fresh water, sea water and industrial soil.

5. COMPARATIVE ANALYSIS

In each life cycle stages, comparative emissions in both the technologies are shown in Table III. In raw material preparation stage the results show that input resources utilized for the production of PCB and Printed RFID antennas are 95% and 5% respectively. Hence we can save resources by 95% while implementing printed technology instead of PCB technology. Similarly the environmental emissions in the raw material preparation stage depicts that only 1% of emissions occurred due to printed technology while remaining 99% of emissions occurred in production of antenna using PCB technology.
In production processing stage, the results show that the quantitative measure of input resource consumption is significantly lower in production of antennas using printed technology. Similarly the environmental emissions depicts that only 2% of emission occurs in one million production of antenna using printed technology while remaining 98% of emissions occurs in the case of PCB technology. Observing the intent data in Table III clears that each component (to air, fresh water, sea water and industrial soil) of emissions is sky-scraped relative to printed technology. We have explored the end of life cycle stage of polymer RFID antenna. The results include both incineration and land filling processes. The total emissions for the production of one million units are 2258 kg in incineration process and 792 kg in land filling process. Hence land filling process is devisable to minimize emissions.
6. TOXIC EMISSIONS

Here toxic emissions in raw material preparation stage have been illustrated. We are focused on exploring hazardous emissions within inorganic emissions to air in each technology. With production of 1 million printed RFID antennas, it is evident that the toxic gas such as carbon dioxide, carbon mono-oxide, hydrogen, nitrogen dioxide, nitrogen oxides and sulphur dioxide are evolved during the raw material preparation stage. The amount of different toxic gas emissions are shown in Fig. 6. The emission of carbon dioxide is largest among all toxic emissions. Similarly in a production of one million PCB antennas, it is evident that the toxic gases are evolved during the raw material preparation stage. These different toxic gas emissions are shown in Fig. 7. The mass of different emissions are as follows. Carbon dioxide - 89530 kg, Carbon monoxide - 62 kg, Hydrogen - 583 gram, Nitrogen dioxide - 150 gram, Nitrogen oxides - 211 kg and Sulphur dioxide - 728 kg. Beside these toxicants, there are also few emissions which are not illustrated in Fig. 7. The amounts of these toxic emissions are significantly low even than masses of nitrogen dioxide and carbon mono-oxide. In Figs. 6 and 7, the amount of toxic emissions in each technology reveals how severe toxic emissions in case of PCB antenna compared to printed RFID antenna.

7. CONCLUSION AND FUTURE WORKS

Our research makes several important contributions. Obvious practical implications of our results show that technology wise RFID printed antenna causes less harmful and hazardous impacts to the environment. We performed the modeling based on conventional PCB technology and polymer substrate printed RFID technology. These two technologies have been compared in terms of input resources utilization, and emissions to air, fresh water, sea water, industrial soil and hazardous emissions. After several iterations of database analysis we reached to a conclusion that printed electronics materials are environment friendly.

There are many avenues for further research. The first important future work is to reflect on optimization of technology. There are tremendous amount of parameters that need to be consider during LCA process. One should focus on each parameters of the life cycle assessment and see how severe their significance is. Another imperative future work is to consider the recyclablility and end of life issues of PCB antenna to achieve the complete cradle to grave life cycle assessment. Finally, it would be worthwhile to examine the role of resources utilizations in manufacturing process of printed and PCB antennas.

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