A Literature Review on Energy Information System Software Development: Research Gaps and Questions in Industrial Manufacturing

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Abstract. In recent years, energy information systems (EIS) have become a growing area of research interest in industrial applications. In this article, we assume that the majority of scientific papers on EIS for industrial manufacturing are neglecting the software development aspect. Therefore, this article performs a systematic literature review on energy information systems for energy-aware industrial manufacturers. One of the main findings is that there are few scientific achievements for this research area. To support this, current research gaps of and questions for energy information systems are proposed.

Keywords: energy information system, energy consumption, energy efficiency production, literature review, industrial manufacturing.

1 Introduction

The improvement of energy efficiency is a key challenge in the industrial sector, especially in industrial manufacturing [1]. This can be observed, for example, in industries such as the steel, paper, chemical, or cement industry [2–4]. In the context of sustainable and cleaner production, a substantial amount of industrial manufacturers are confronted with the second key challenge of emission management. Therefore, the analysis and reduction of emissions (e.g. carbon dioxide or NOx), and the improvement of the energetic footprint of the products in the industrial manufacturing process are addressed by researchers [5–7].

From an energy perspective, there are even more challenges. There are always political, social, environmental [8–10], and technological drivers [11] that are influencing energy behavior. The consideration of all aspects at the same time enables the process of decision-making and changing the energy behavior in an industrial process [12]. The outlined key challenges can be addressed by energy information system (EIS).

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We are following the definition of EIS as "organizational-technical systems for systematically obtaining, processing, and making available environmental information available in companies" [13]. However, the term environmental information describes a large concept. In the context of this paper, the term energy data is more precise. Therefore, we are using the term energy data in this article to describe every relevant and measurable energy type in the context of an industrial plant.

Instead of developing an EIS individually for every industrial manufacturer, reusable information systems with well-defined architectures and software paradigms might be able to gain crucial benefits. In this paper, we assume that this aspect of systematic software development for EIS is neglected in the scientific literature. Therefore, we perform a systematic literature review on EIS for industrial manufacturers to identify the current scientific gaps and questions.

This paper is divided into four parts. After this section, the next part moves on to describe the research methodology for the systematic literature review. In the third part, the results are presented and discussed. Finally, the paper concludes with a summary of the findings.

2 Methodology

In this paper, a systematic literature review was performed. The results will be used as a foundation for future research projects. The article was following the methodology for literature reviews from Kitchenham [14] and the guidelines from Webster and Watson [15]. We aimed to give an answer to the following research question:

- What are the current research gaps and questions for EIS software development research in the context of energy-aware industrial manufacturing?

In the beginning, a keyword search in EBSCO BSC, EBSCO ASC, SpringerLink (SL), AIS Library (AIS Conferences and WI), and ScienceDirect was performed. In addition, a manual search for the MKWI was conducted (from 2003 until start of research in February 2016). The keywords were (including German equivalents): environmental management information system, energy and carbon management system, environmental decision support system, energy data information system, energy information system, energy management information system, energy data management, energy process data, energy efficiency production, energy supply chain management, and energy procurement.

This resulted in 3680 articles from peer-reviewed academic journals that were filtered in two exclusion phases. In the first exclusion phase, duplicates were eliminated and the titles and abstracts were read. 291 articles remained (study selection and study quality assessment).

In the second exclusion phase, all of the 291 articles were read and checked for suitability (the subject of the article had to cover industrial manufacturing and EIS). This resulted in 131 articles. To ensure that all relevant literature is included, a backward search was performed (repetition of study selection and study quality assessment). This led to 158 articles from more than 60 different academic journals and proceedings.

For the data extraction process, the articles were coded by their methodological direction. The methodological codes are: model development (mathematical), model development (non-mathematical), method construction, survey, case study, experiments, literature review. Combinations of codes were allowed. The methodological code for non-mathematical model development is used for actual modeling and not tool development.

3 Results and Discussion

This research examined the remaining 158 articles by performing a statistical meta-analysis over the literature first (see Fig. 1). The meta-analysis shows that only 38 articles were published from 2003 to 2009; furthermore, it can be seen that only one article was found in 2005. However, there was a significant increase of articles published in 2010 (16 articles), followed by a small decrease in the next two years (12 and 13 articles). Since 2013, the articles published are increasing, indicating a growing importance of EIS research in an industrial context (79 articles from 2013 until February 2016).

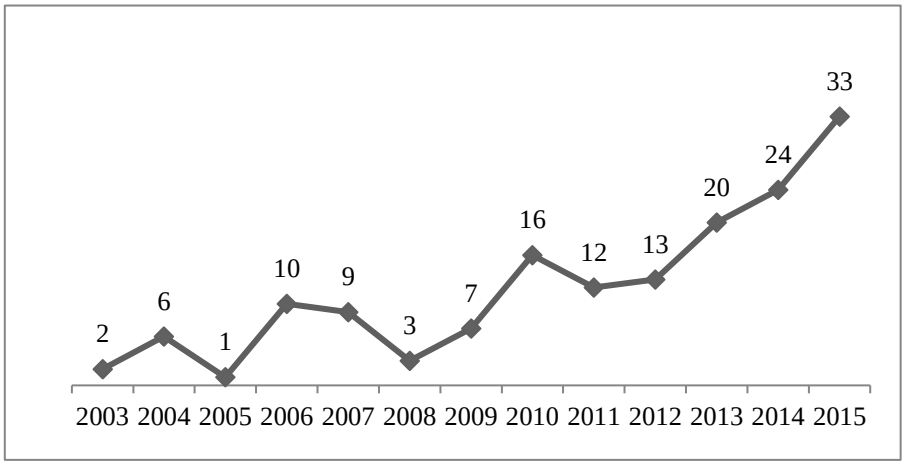

Figure 1. Articles published per year (numbers are shown for full years from 2003 to 2015)

On the one hand, this might be due to the commitment of the European Union to reduce emission of greenhouse gas by 20%, increase energy efficiency by 20%, and increase the use of renewable energies by 20% [16]. On the other hand, climatic catastrophes, such as the explosion of Deepwater Horizon in 2010, were leading to more ecological awareness in politics. Governmental grants as well as agreements in the UN Climate Conference helped to improve energy efficiency and to support research [17, 18]. In other words, the political and environmental factors might be influential for an increasing amount of research since 2010.

In the next step, we analyzed the paper by their methodological direction. In an article, multiple methods can be applied. For this reason, the number of methodological directions can be greater than the total number of 158 articles. Approximately 67% of all articles are trying to develop a model and 54.43% of all articles concentrated on using single case studies to evaluate their results. 74.53 % of these modeling papers are focusing on a mathematical model, hereby showing that those are the methods most commonly used. Five percent of the articles used surveys and 1.9% performed experiments in their paper. In 34.81% of the articles, a literature review is performed as the foundation for the specific research.

The construction of methods (2.53%) and non-mathematical modeling (17%) can be classified as design science. This shows that the actual software development and modelling of EIS does not have the highest priority in the research area. This can be explained by the high usage of single case studies in the articles; this suggests that EIS are development individually.

3.1 Research Gaps

We identified two articles that had a similar scope to our research. El-Gayar and Fritz [19] and Watson et al. [20] identified several important research gaps and questions that focus on the software development aspect of EIS. Watson et al. are presenting the research gap of increasing energy efficiency by integrating supply and demand data, the usage of information systems to change social norms, and the report of information to governments [20]. El-Gayar and Fritz are showing several research gaps including the need for identifying specific informational needs, the influence of environmental and business processes on EIS, and the nature of environmental information and the capturing of such data [19]. However, during our literature review, we were able to identify more research gaps and questions. These new gaps and questions will be presented next.

The main usage of single case studies is resulting in individually developed EIS that are not reusable. It can be seen from the meta-analysis that these EIS are used to apply methods for one specific instance of one problem. The main usage of case studies suggests that reusability and software development process of EIS is not one of the current main concerns and neglected. In addition, it can be seen from the literature that only a limited amount of methods and insights from information system research is used. A stronger collaboration of both research areas would be beneficial for researchers and practitioners.

As can be seen from the literature, there are modeling approaches for the analysis of energy and machine (process) data [21]. However, there is a substantial amount of unused potential in combining these two types of data. An industrial manufacturer might be able to increase his energy efficiency by adjusting his machines as well as to change flexible parts of production processes and shifts to save energy costs and improve the usage of his own energy production. Research in demand-response programs are addressing this topic partly, primarily focusing on the mathematical and price-side of the market, therefore neglecting the energy information system that is needed for these calculations as well as possible partnerships between different market participants [22, 23].

For example, through cooperation between consumers and retailers, energy consumption forecasts might be improved, therefore enabling optimized energy procurement and adding value for both sides [24]. These approaches can be further investigated by scientists to develop a holistic approach. This can be achieved by defining a reusable information model for energy and machine (process) data in industrial manufacturing.

In addition, the incorporation of constantly changing requirements should be supported by the developed and existing reference models. These can be used to develop a reusable architecture or architecture description. In the last years, the modeling community is using several approaches for standardizing information systems through reference architectures or architecture descriptions that can be applied for EIS [25, 26].

3.2 Research Questions

If the scientific gaps are addressed by the scientific community, EIS software development might benefit from scientific achievements. This could lead to further optimization of industrial manufacturers. To be able to address this problem, we formulated the following two future research questions (**RQ**) in addition to El-Gayar and Fritz [19] and Watson et al. [20]:

- **RQ01:** What are the design principles of a reusable information model focusing on the combination energy and machine data?
- **RQ02:** How can the development of a reusable architecture for EIS in industrial manufacturing be supported?

4 Conclusion

The aim of this study was to identify new research gaps and questions regarding the software development aspect of energy information systems. This research area is still young and therefore dominated by the use of case studies instead of empirical data. The results suggest that there is an overlooked potential in this field of study. However, the importance of EIS is growing and future scientists are encouraged to perform research to expand on the identified scientific achievements.

In addition to the already identified research gaps and questions by El-Gayar and Fritz [19] as well as Watson et al. [20], we were able to identify several new research gaps that lead to two new research questions regarding the combination of energy and machine data as well as a potential reusable architecture for EIS development. Therefore, the search for answers to these research questions is the next logical step.

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