Automated environmental impact assessment (EIA) via asset administration shell

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Abstract. Due to growing public awareness and rising requirements of legislation and customers' expectations in the field of sustainability, it is increasingly important for enterprises to assess and subsequently reduce their environmental impact. However, the acquisition of environmental data in enterprises still causes considerable effort, due to the necessary manual acquisition.
A unified asset administration shell (AAS) potentially provides higher data transparency and environmental data interoperability along the value chain and, thus a more detailed (real-time capable) accounting of the environmental impact of products and services. Hence, this paper presents an approach for an automated environmental impact assessments (EIA) of products and production sites via AAS. Thereby, a first application of the AAS in the context of automated EIAs was implemented at the ARENA2036 research factory. The AAS automatically collects energy and emission data throughout a production process and thus allows the allocation of actual emissions to product and equipment (environmental wallet). The results reveal a first starting point for automated EIA, facilitating individual EIAs to address increasing product variety.

Keywords: corporate sustainability, environmental evaluation, digital twin.

1 Introduction

Increasing requirements of legation, public awareness and customer expectation drive the sustainability efforts of enterprises. Various enterprises react to these requirements and, for example, set their own goals for decabonization [1, 2]. On the long term, climate neutrality along the value chain, i.e. for suppliers, will therefore become increasingly important and a competitive factor. Also further environmental impacts, e.g. resource consumption, are receiving more attention and will have to be addressed convincingly by enterprises. Environmental impact assessments (EIAs), based on the determination of the current environmental impact caused by a company's activities, are thus becoming indispensable. However, the acquisition of environmental data in enterprises still causes considerable effort, due to the necessary manual acquisition procedures. Currently only few automated systems, e.g. in the form of energy monitoring systems exist.

In this context, the wide-spread efforts into unified Asset Administration Shells (AAS) represent a promising approach for automated EIAs of products and production sites. An AAS potentially provides higher data transparency and environmental data interoperability along the value-added chain and thus a more detailed (real-time capable) accounting of the environmental impact of products and services. Although the general potential is indicated in the German Standardization Roadmap on Industry 4.0, there is no detailed discussion about the potential or an initial implementation for automated EIA. Therefore, this paper addresses the following research question: How can the AAS be used for EIAs?

To answer this research question, this paper is subsumed into five sections. Following this section, the state of the art is presented divided into EIA within enterprises, usage of AAS and the comprehensive use of AAS for EIA. Sections 3 and 4 substantiate the application of the AAS for EIA by presenting an initial implementation of an AAS for energy consumption and CO_2-emissions. The results show the specific energy consumption and CO_2-emissions of the assembly process of two different products. Section 4 describes the limitations of the intended research and open question. Section 5 concludes with a summary and outlook.

2 State of the art

2.1 Environmental impact assessment (EIA) within enterprises

According to [3], EIA is defined as "an assessment of the impact of a planned activity on the environment". To date, numerous approaches to EIA exist in literature and industrial practice [3]. On the one hand, companies need EIAs for their internal decision-making processes concerning product and production decisions. On the other hand, an increasing number of companies have to publish information to stakeholders externally, e.g. in the form of sustainability reports. In the future, CO_2 labelling of products could become mandatory, in analogy to already existing energy labels.
The most widely used method for EIA is Life Cycle Assessment (LCA) [4]. This standardized method enables the determination of environmental impacts of a product or entire company. However, when applying the method, various assumptions and simplifications have to be made, so that the results cannot be easily compared. Furthermore, especially due to the detailed consideration of all life cycle phases, the data acquisition causes high efforts and requires huge databases. Here only average values, e.g. for raw material mining or production of exemplary products, are available [5, 6]. Although these average values considerably reduce the effort for data collection and make a complete LCA of a product life cycle possible in the first place, it nonetheless inhibits an accounting based on the actual environmental impacts [6]. Further methods for EIA are e.g. Material Flow Cost Accounting or specific environmental performance indicators [7]. The data collection shapes the basis for each EIA and is a prerequisite for a valid and meaningful assessment [8]. In a best case, the environmental impacts can be directly assigned to products or the processes that cause them. For decision support, it should also be possible to analyze the data in close-to-real time. However, there are

currently hardly any approaches to structurally organize the acquisition and transfer of environmental data in companies [4].
Without the support of digitization or software, the acquisition and structuring of sustainability data in companies is hardly possible [9]. Software support and information systems for sustainability assessments, such as LCA software or software to support the preparation of sustainability reports, have been developed [10]. However, in most cases, these do not allow for real-time monitoring of data or are very specifically designed for individual use cases, such as energy monitoring. An extension of systems already in use, like ERP-System, have been suggested. Mostly these can only provide a small fraction of the data required for an EIA, e.g. material data [11, 12]. Thus, they do not fulfill the requirements for a complete and efficient EIA within manufacturing companies.
A structured data recording of environmental impacts in production, which allows a direct assignment to product or process and a real-time analysis, does not exist today. Therefore, it is necessary to develop a new approach that meets these requirements.

2.2 Usage of AAS

The approach of an AAS can by derived from the approach of an industry 4.0 component (I4.0 component). The I4.0 component combines an asset (e.g. a machine or a machine sensor; the granularity is application-dependent) and a virtual interface, which is referred to as AAS [13]. The AAS bundles functions and data via sub-models, which can be delivered as active or passive implementation [14].
The reference architecture model for the I4.0 component referes the entire life cycle value stream, which includes the product development, production, operation and recycling process [15]. The requirements for an AAS can be found in [16]. Several works [17, 18] have demonstrated the potentials of application of the AAS in various manufacturing areas.
Wenger et al. demonstrated the PLC connection by using an asset administration shell for configuration purposes [19]. Lang et al. propagated the introduction of sub-models within the AAS for blockchain technology, which serves as security component during the plug and produce approach [20]. Additional work has been carried out by Lang et al., where the AAS has been used for maintenance procedures [21]. Al Assadi et al. presented an AAS for human workers in production, which included worker preferences to improve the human-machine-interface [22].
The AAS has not been used as an enabler for automated EIA. However, an energy efficiency sub-model has been mentioned in [16]. Further explanation or detailed discussion is missing. According to [16] a potential source of the sub-model can be the ISO 20140-5.

2.3 AAS in the context of EIA

In order to apply AAS for EIA, it is first necessary to develop a general picture on how an AAS may be used for EIA. Thereby, intra- and inter-company aspects have to be differed in relation to the features of AAS. The interrelation between features, advantages and the resulting intra- and inter-company applications can be seen in **Fig. 1**.

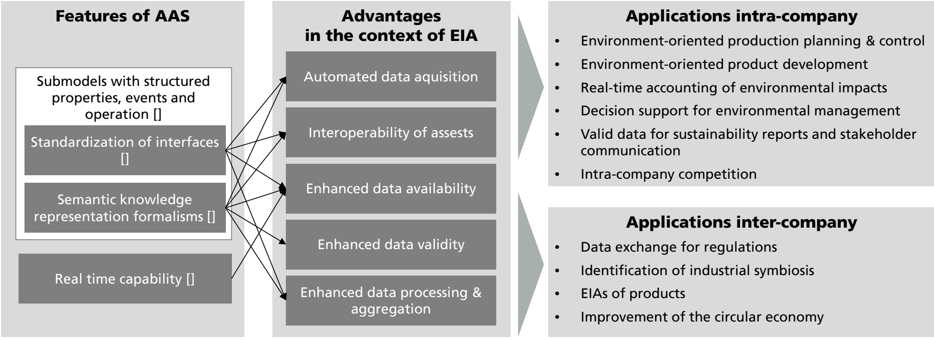

Fig. 1. Features, resulting advantages in the context of EIA and possible intra-/inter-company applications of AAS

Sub-models contain structured properties, events and operation, which include a self-description for automation purposes [23, 24]. This includes the standardization of interfaces and semantic knowledge representation formalism, which enable interoperability across components or factories. The automated data acquisition reduces the manual efforts [25]. A standardized data structure of assets facilitates the data processing and aggregation and thus, supports decisions by improving the data basis. The data content of AAS is enhanced successively during the planning, runtime and recycling period [26].

Within the company real-time capability enables control, decision-making and modifications while running production and a faster detection of anomalies or errors which can lead to an environment-oriented production planning and control. Higher data availability within production and, if applicable, of additional product life cycle phases, like usage or end of life, can enable an environment-oriented product development. Due to the detailed and structured data acquisition, resource consumption and monetary as well as environmental costs can be assigned to the corresponding cost center. Further applications are sustainability reports and intra-company competition, e.g. for a minimization of CO_2.

Inter-company applications in the context of EIA can be data exchange for regulations (e.g. REACh, RoHS, WEEE) or possible identification of industrial symbiosis. An EIAs of products can be enabled and the manual effort drastically reduced so that a LCA for products can be automated and based on real data, which subsequently could be used for product labels. By providing information on product composition, use circular economy can be accelerated.

3 Implementation of the AAS for EIA

In order to enable an automated product related allocation of CO_2-emissions and energy consumption, the implementation of the presented approach requires three AAS. Namely one AAS for the robot and one for the energy logger, compare **Fig. 1**. A third AAS serves as EIA service in which the power and energy consumption as well as CO2 footprint is calculated.

The AAS of the robot contains the robot process related properties (e.g. joint positions, torques and forces) and the lable of the current product programm. This additional information serves as allocation point for the product related energy consumption and CO_2 emission. Technically, the AAS approch of Ewert et. al [18] is applied. The Message Queuing Telemetry Transport (MQTT) serves as communication protocol for the demonstrated use case. The different assets are publishing, respectively subscribing MQTT topics, compare **Fig. 1**.

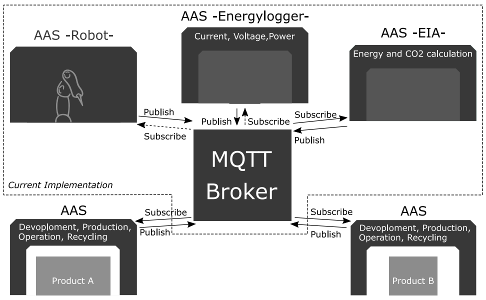

Fig. 2. The implementation setup of an automated energy / EIA via AAS

4 Result

Fig. 3 illustrates the graph of electric power over time (dark orange) and cumulated CO2 emissions (purple) during an experiment of 7 minutes, where two different products (A & B) are assembled. The tact time of an assembly can be considered to be 3 minutes and 20 seconds, 1 minute and 10 seconds respectively Fig. 3 shows that during assembly, the power ranges between 210 and 243 Watt. The different path velocities of the robot program causes the fluctuation in power consumption. The steady state is justifiable by the constant power consumption of the robot controller in idle mode.The linear approximation of the cumulative CO2 emission shows the different slope/gradient of the increasing CO2 emssion during assembly. The cycle time of the asmmbly takes 3 minutes and 20 seconds for A, 1 minute and 10 secondy for B respectively. The resulting emission of carbon dixide during the assembly of A is 5 gramm, whereas the assembly of B is 2 gramm.

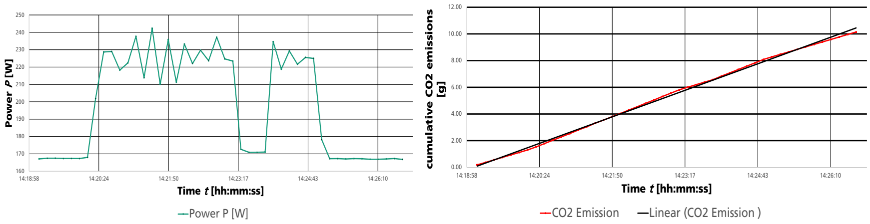

Fig. 3. Electricpower curve and culmative CO_2 emmisions during the assembly of product A & B

5 Discussion

This paper showed the potential of AAS in context with energy and CO_2 emission tracking. The further allociation of emissions to specific products opens up the window to foot print calcations.It seems that there is a linear relationship between cycle time and CO_2 emissions, however we conducted a short and simple assembly process. We expect a non-linear relationship between cycle time and CO_2 emissions in case of an entire production job. For reasons of poor data availability of the specific CO_2 emissions due to different energy sources, we have used the average value of 401 grams CO_2 emissions per kilowatt hour of the specific electricity mix in Germany [27]. Further work will take into account the individual power supply and higher data resolution, which can be easily integrated within the service-oriented approach of the AAS. The adjustments will result in improved accuracy of the caused CO_2-emissions estimations[1].
The described approach demonstrates the ability of product-related sustainability footprint tracking in the context of energy consumption and CO_2 emissions. Although, the general potential of an AAS in the context of EIA and implemented an AAS for the monitoring of CO2-emissions of an assembly processs has been shown, the following research questions remain unanswered. These questions need to be addressed in future research in order to develop and evolve the full potential of AAS for EIA:

- Which data for EIA acquired by AAS could create added value for companies, societies, communities, authorities, customers or other stakeholders?
- How could data for EIA be semantically described and structured in order to create a semantic submodel for EIA?
- Which new services or business models are enabled via AAS in the context of EIA?
- How can a production process be environmentally optimized by applying AAS?

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[1] The specific CO2 emissions of purchased electricity are available as 15 minutes average calculated by energy supply companies.

6 Summary and outlook

This paper presented the potential of the AAS regarding an automated EIA. Besides the presentation of the state of the art of EIA and AAS, features and advantages of AAS in the context of EIA were adresssed. A first demonstration and calculation of the product specific carbon dioxide emissions of a assembly process have been performed. Results show that the real electric energy consumption and CO_2 emissions can be assigned to the product using AAS. This highlights the usability and advantages of using AAS for EIA. However, there are some limitations of the preliminary implementation which are emphasized within the discussion. Furthermore, still unanswered research questions according to AAS and EIA are highlighted.
It is intended to pick up these unanswered research questions and eliminate some of the limitations of the research described. In analogy to the described approach in production tracking, the usability of AAS for EIA of products should be further demonstrated by extending the tracking of CO_2 emissions to the entire production.

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