Environmental Management Systems: a platform towards a Digital Product Passport reality

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Digital Product Passports (DPPs) are the tool that The European Commission aims to develop and put into usage in the fight against climate change and greenhouse gas (GHG) emissions at a manufacturing and operational level. As their development is on-going in this "marathon" against time, a consensus about data structure, granularity, protocols, infrastructure and accessibility, among other specifications, is targeted to be reached by 2026, when battery-related products are the first that should have DPPs attached to them. The current process of gathering and inserting the previously mentioned data (up to the current legislative standards of the European Commission and other trade institutions) is mostly reliant on the manufacturers and suppliers, whilst gathering data from the usage part of the product's life cycle has proved difficult. The data is also stored on several non-centralized databases, with varied degrees of granularity and relatively unilateral data flow. This thesis aims to analyse the angle of how Environmental Management Systems can help to bring widespread DPP implementation closer to reality by providing a starting point for any size of enterprise and how newly active directives will affect research and policy-making in this domain. One such directive is the Corporate Sustainability Reporting Directive (CSRD), established by the European Parliament, aiming to standardize sustainability reporting. Following an exploratory literary review, this thesis seeks to bring forward a proposal aimed at companies which will lead to a smoother process and transition to the DPP standard.

Additional Key Words and Phrases: Digital Product Passport, Environmental Management Systems, information requirements, manufacturing.

1 INTRODUCTION

DPPs are a solution already put in motion by the European Commission in hopes to tackle emissions from the manufacturing and distribution systems, but also looking to improve the end-of-life stage of devices (refurbishment, rare metal extraction, recycling). This is achieved by tracking different types of information along a device's life cycle [6]. The research of how a DPP system would function in a real context is still in progress, case in which information requirements, protocols, IT infrastructure, legislation among other details need to be decided and implemented. Environmental Management Systems (EMSs) are frameworks used in the context of companies that aid monitoring, controlling and creating policies in regards to environmental performance.

The gaps that this thesis aims to address could provide a new angle in terms of DPP implementation. The problem which this thesis studies is how EMSs can be used in order to fulfill operational and information requirements of DPPs.

This research's proposal focuses on two aspects: firstly, a proposal for an enhancement to the as-is material flow processes that has been previously highlighted by Weisner et al. [35]; secondly, guidelines for companies that seek to make use of EMS capabilities to aid their environmental reporting, batch tracking during the material flow process and future-proofing for the implementation of DPPs.

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Validation of the proposed solution would come in the form of a Case Study of a company that could benefit from the implementation of an EMS in their material flow process. The Case Study will appreciate how the guidelines would be applied in the company's context in order to improve the relevant aspects of their operations.

In order to explore the ways in which EMS' can support the information requirements of DPPs and even how they can become a cornerstone in the foundation of DPPs, this thesis aims to understand several factors: the data and informational basis of DPPs, the inner workings and capabilities of Environmental Management Systems, in the real-world context in which these systems function. As such, the structure of the paper is as follows: Section 2 introduces the research methodology, Section 3 presents the concept of the DPP, Section 4 focuses on the concept of EMSs, Section 5 approaches the view of EMS as pathway towards DPP implementation, Section 6 proposes an improvement of the current manufacturing process, alongside a set of guidelines towards the usage of an EMS that can lead to aforementioned manufacturing improvements, Section 7 looks to validate the findings by placing the recommendations in a scenario of a real world company and Section 8 promotes a discussion based on the findings, as well as looking into future research recommendations.

2 RESEARCH METHODOLOGY

2.1 Research Question

In order to achieve the goals of determining how EMS can work towards DPP implementation, the following research question was formulated: **How can an EMS support the information requirements of DPPs?**.

Sub-Research Questions:

(1) What are the information requirements of Digital Product Passports?
(2) What are the main capabilities of Environmental Management Systems?
(3) How can Environmental Management Systems capabilities be mapped to Digital Product Passport information requirements?

Following the answering of the research question and the further broken down sub-questions, this thesis aims to establish guidelines as a result of the conclusion of the mapping process (from EMS capabilities to DPP information requirements).

2.2 Research Methodology

In order to create and establish guidelines that can make complete and efficient use of EMS capabilities towards the implementation of DPPs, the Design Science Research Methodology (DSRM) can be employed. According to DSRM, the design problem at the focus of the thesis is as follows:

Improve: *standardized adoption of DPPs for products*

by (re)designing: *guidelines on how enterprises alongside the supply/ value chain can manage DPP information using EMS* in order to: *improve the DPP information collection process, environmental reporting and prepare the implementation of DPPs for companies*

The research process consists of an exploratory literature review in order to cover as much of the information in suitable depth. In the end, an improvement proposal has been brought forward in the process of manufacturing, alongside a guideline proposal. The latter would help establish preliminary steps that companies have to take for the integration of EMSs into their efforts of complying with the European DPP project.

3 DIGITAL PRODUCT PASSPORT

3.1 What is it?

The concept of DPPs has been a subject that has gained increasingly more traction in the current socio-economic climate in which authorities have been attempting to resolve the broad issue of climate change. DPPs are meant to be a solution to environmental sustainability and circular economy [14] [18] in a manufacture-inclined global economy, case in which DPPs keep track of materials used in the manufacturing process, product life cycle and maintenance records, energy efficiency, chemical composition [6] and more from an non-exhaustive list that relates to the product's use and sustainability metrics.

3.2 DPP Information Requirements

DPP's role as a measure for tracking and accounting ecological impact for each product it is attached to implies the highlighting of several requirements that need establishing. As DPPs are aimed towards a general use in products, the focus of the information requirements will be aimed towards the needs of batteries and battery-related products (because of their relevance in the short-term future).

The identified legal background of data disclosures for suppliers and manufacturers, in accordance with the European Regulation [23] [26], and in correlation with existing studies [19] is as follows:

(1) **Manufacturer Information:** Name, registered trade name or trademark, postal address, single point of contact, website, and email address.
(2) **Battery Identification:** Model identifier, batch or serial number, product number, or other unique identifiers.
(3) **Battery Type and Chemistry:** Specific category, type, and chemical composition.
(4) **Manufacturing Date:** The date when the battery was manufactured.
(5) **Hazardous Substances:** Presence and concentration of hazardous substances, including critical raw materials.
(6) **Capacity Marking:** For rechargeable batteries, the capacity must be clearly marked.
(7) **Minimum Average Duration:** For primary batteries, the minimum average duration of discharge.
(8) **Recycling and Repair Information:** Symbols like the crossed-out dustbin to indicate mandatory separate collection of waste batteries. During repairing or refurbishment processes, process details, overview of new/ old parts and repairer information should be linked to every process.
(9) **CE Marking:** To indicate conformity with health, safety, and environmental protection standards for products sold within the European Economic Area.
(10) **Carbon Footprint:** Data on the carbon footprint of the battery throughout its life cycle.
(11) **Performance and Durability:** Information on the battery's performance, lifespan, and durability.
(12) **Due Diligence:** Reporting on due diligence processes concerning the sourcing of raw materials.
(13) **Minimum Recycled Content:** Information on the minimum recycled content for critical minerals used in the battery.
(14) **Labeling:** Batteries must be labeled with the name of the manufacturer, type of battery, date of manufacture, and information that facilitates recycling or reuse.

The implication of the Right To Repair EU Directive [25] and the GDPR [24] is that, during processes in the supply chain, maintenance and discarding later on in the product's life cycle, employee personal data must be kept secure and compliant with privacy regulation.

Beside the legal requirements of product information disclosure that would systematically become part of DPP information requirements, several other functional and operational requirements have been outlined [19]:

(1) **Unique Identifier:** Implications of underlying IT infrastructure dedicated to DPPs point towards the establishment of a central registry for a unique identifier, which is required for linking the DPPs to their associated physical objects [19]. Candidates for the role include the product model (e.g. product model A), batch (e.g. product A, from plant X in year 2023) or item (e.g. product A, Serial number 12345678910) [35].
(2) **Value Chain compatibility:** The DPP systems should be designed towards improvement of supply chain (information) transactions, without hindering existing value chain processes (i.e. value chain actors enter information/ statements at the step for which they are exclusively responsible for)
(3) **Security:** The information exchanges that take place in the DPP system must be secure, verifiable in regards to their origin, integrity, responsibility, with all changes recorded, trackable and immutable (records should not be overwritten)
(4) **Accessibility:** The system should distinguish between different levels of authority, in order to facilitate hierarchical access where needed (i.e. authorities should be able to access certain data about a company's products, and not competitors).
(5) **Flexibility and Interoperability:** The system must be flexible to adapt and evolve as the regulation and environmental landscape evolve over time, and it must be accessible from different software systems, under a standardised manner.

3.3 CSRD towards the implementation of DPPs

An important development in this field is marked by the Corporate Sustainability Reporting Directive (CSRD) by the European Parliament [22]; the directive establishes guidelines for corporate sustainability reporting. Its aims are to enhance and standardize the disclosure of sustainability information by companies to ensure greater transparency, consistency and comparability. The achievement of these goals hopes to cement a common set of standards for EU-active companies.

The directive [22] targets large companies, including non-EU companies that have significant activity in the EU. The high-level aims of the CSRD are decoupling of economic growth from resource use, aligning of corporate activities with the EU's climate neutrality goals and ensuring a sensible transition towards a sustainable economic system [22]. Key elements emphasized in the directive are of environmental, social and governance nature, all within set timelines in regards to reporting and implementation, for both small and medium enterprises (SMEs) and large scale companies; organizations as such are required to include information related to climate-related risks that their practices might incur, details about the business model's resilience to sustainability risks and opportunities related to sustainability.

There is a growing encouragement towards digitalization of the means of reporting to enhance accessibility and usability [22]. This also suits the needs that DPPs would present to be able to function effectively in a business environment. All companies required to follow the CSRD (at the moment only mandatory for large companies) have to follow the European Sustainability Reporting Standards (ESRS)[5]. The standards are designed to be applicable to all sectors and types of companies, with a focus on double materiality and with an aim to fit multiple existing global sustainability frameworks[5].

The application of the CSRD starting 1st of January 2024 [22] and implicitly ESRS is a clear effort to pave the way towards a wide adoption of DPPs by mandating policies that fit the standardization and application of data norms required by DPPs.

4 ENVIRONMENTAL MANAGEMENT SYSTEM

As this paper is continuing research efforts of peers, based on future work suggestions, an important step is analysing how companies use their Environmental Management System (EMS) and how can that be tied to DPPs.

Environmental management is the "management of those activities of a firm that have or can have an impact on the environment" [29]. Environmental Management Systems (EMSs) are structured frameworks designed to help organizations monitor, control, and continuously improve their environmental performance. The EMS largely focus on control of water and air emissions and waste disposal [20].

4.1 Capabilities

EMSs are structures that aid organizations in managing their environmental obligations in a methodical manner. The capabilities of an EMS include the formulation and execution of environmental policies, evaluation of environmental impact, establishment of measurable objectives and targets, and development of programs to accomplish these targets. An EMS also guarantees adherence to environmental regulations [1], promotes continuous improvement through monitoring, and encourages internal audits and management reviews to assess effectiveness [20]. Furthermore, EMS frameworks support documentation and record-keeping, promoting transparency and accountability [1]. Public service organization and private companies have reported improvements as an effect of EMS implementation; specifically improvements in organizational structures and procedures for environmental work, planning of environmental projects and documentation of environment management practices [34] [3]. The incorporation of sustainability into business strategies and decision-making processes is another crucial functionality, assisting organizations in aligning their operations with broader environmental objectives.

A case study of how Fujitsu has implemented and it is currently using an EMS [11] is aligned with this paper's findings of EMS capabilities. Fujitsu's data centre operations and its energy consumption are considered as the most significant environmental impact of Fujitsu Australia [11]. The Sustainability Team's job towards the transformation process requires connecting, organizing and integrating of all parts and layers of the company [11], with a fundamental focus on understanding the company's impact, required actions and the efficiency of said actions.

The solution identified was the implementation of a global EMS certified under ISO 14001, with the addition of a local certification [11]. The Fujitsu EMS claims to provide a framework which promotes a systematic approach to meeting environmental objectives. The rigorous "plan-do-check-act" approach, which is independently verified, enhances the likelihood of meeting aforementioned objectives [11]. SAI Global's Damian James General Manager, Assurance Services states that audits have revealed an exceptional level of commitment; Fujitsu ANZ's EMS provides "prevention and reduction of pollution, as well as customer focus and system improvement opportunities through effective implementation" [11].

The "set of goals, KPIs (key performance indicators) and related targets, along with a well implemented internal audit program" are important to monitoring the health and performance of the system [11]. Office locations, warehouse, data centres and distribution centres are part of Fujitsu's ANZ operations, each of them being included in the company's EMS considerations [11]. Besides the ecological impact, the robust environmental management framework has contributed to training 1100 staff, ensuring that sustainability is part of the working mentality of employees [11]. The sustainability related operational changes have resulted in a 18 percent cut in office-generated emissions, and more than 50 percent reduction in travel-related GHG emissions [11]. Additionally, data centre facilities run a PUE (Power Usage Effectiveness) considered best practice for tier III data centres[11]. A tier III data centre has multiple paths for power and cooling and systems in place to update and maintain it without taking it offline; it has an expected uptime of 99.982 percent [9]. Transparency and the conserving of resources are mentioned as key principles in Fujitsu's environmental management approach, with a effective progress monitoring strategy, "which has been recognised in a number of external audits" [11].

Tools such as OpenLCA (open-source software) [15] bolster these functionalities by enabling life cycle assessments and sustainability evaluations, thereby guiding decision-making and reporting. Recently, a new software tool has been developed, aiming "to reliably and verifiably assign the CO2 footprint within transportation and logistics" [28]. BigMile is a tool that "will help companies to better understand and track their logistics emissions" [28], which is also ISO 14083 certified. In the Netherlands, BigMile is part of a pilot group consisting of ten companies, including Bleckmann, Van den Bosch and Moonen Packaging [28]. The pilot group is mapping out how companies can implement this standard and is also coming up with a practical translation of the standard and a verification scheme [28].

4.2 Standards

An EMS by itself is not standardized between different companies; the implementation of an EMS can follow two paths: it can be developed in-house or based on a certified framework. The two most frequently used certified standards are ISO 14001 (international standard) and EMAS (Eco-Management and Audit Scheme, is an European standard) [20].

Key aspects of the ISO 14001 standard include the organization of environmental goals [20], the ensurance of compliance with legislation and encouragement of stakeholder communication and implication [1]. Environmental goals are managed using a systematic policy of implementation and operation, backed up by a structure of responsibility [20]. The desired level of accountability, active policy-making and resulting action is enabled by strict environmental management documentation [20]. The inherent internal and external communication capabilities of such a system as ISO 14001 provides a good starting point from where companies can start supplying DPP data concerning their environmentally impactful activities (e.g. raw material extraction process generates *the following amount* of CO2 quantity, tied to *the following responsible managing personnel*). At the same time, ISO 14001 includes provisions for creating a system of checking and corrective action that includes monitoring and measurement, reporting non-conformance, taking corrective and preventative action, and record-keeping with regard to environmental management [20].

ISO 14083 is an international standard, part of the ISO 14000 family of standards; ISO 14083 provides guidelines for the quantification and reporting of GHG emissions from transport operations [2]. The specifications of the ISO standards, in turn, provide a good framework for the audit process that can be applied to DPPs. Another point of consideration is the assignment of different access levels to different types of stakeholders (environmental authorities, competitor companies and consumers). This can be achieved by establishing alongside authorities which information is relevant to the public and which needs to be protected under the guise of trade secrets (exclusive to environmental authority access).

The main differences between ISO 14001 and EMAS are that EMAS is issued by a public body while the ISO 14001 standard is a private norm . This means that public authorities are formally involved in the EMAS scheme [31], resulting in a stricter regulation and more stringent requirements on external communication. On the other hand, ISO 14001 is issued by private bodies (environmental verifiers), but these certifiers are approved by each country's standard overseer [31]. A second difference is the spread of these environmental standards: EMAS has gained international validity only since 2010, meaning that countries outside Europe are more likely to be ISO 14001 certified. Because of the required yearly update of EMAS-certified companies to their Environmental Statement, EMAS is considered a better tool to communicate the environmental commitments of companies to external stakeholders [31].

EMSs require corporations, more explicitly (EMAS) or more implicitly (ISO 14001), to set ecological goals in a transparent way; but many companies set targets long before they formalised their EMS [30]. In the same empirical investigation, Steger also comes to the conclusion that the implementation of (standardised) EMS does not lead to dramatic changes in goal setting [30], implying that companies would have achieved their environmental goals anyway, regardless of the EMS. Other results of the investigation performed by Steger point to the fact that there is no visible or measurable difference in environmental performance between EMAS, ISO 14001 or company specific systems [30].

Alongside the most used EMS certification standard, several other that are not as prevalent include alternative models for EMSs in small- and medium-sized enterprises: Ecoaction 21, Ecolighthouse, Ecomappin, Ecoprofit, and Ekoscan [17][7].

5 EMS AS AN ENABLER OF DPP IMPLEMENTATION

In order to provide a clearer view on how the EMS information can be used in supplying DPP information, an analysis on the Europol EMAS Environmental Statement 2023 [10] has been conducted. In Europol's analysis regarding environmental performance indicators, the following (high-level) metrics have been analysed: total tonnes of CO2 equivalent emitted, total energy building (MWh), total water consumption (cubic meters), total waste generation (tonnes), total paper consumption (tonnes), proportion of total land that is nature-oriented (percentage). In-depth analysis is further made on every metric. For example, GHG emissions are further broken down into building energy consumption, vehicle fleet, refrigerant losses, purchased energy, indirect sources (business travel by air and rail). Even though Europol is not by any means a manufacturing or supplying company, the availability of such environmental data and capability of subdividing it into detailed reports of several categories is proof that, under the direction of an EMS (whether that is ISO 14001 or EMAS certified or company specific), such high-standard of reporting is possible. Data such as tonnes of CO2 equivalent emitted in the extraction of raw materials, transporting and manufacturing (information which can be extrapolated to a per-product basis), alongside already supplied data (for legal compliance reasons) about hazardous materials, battery life cycle etc. (refer to Chapter 1.1 Legal Requirements) fit in perfectly to the DPP information requirements and such a transition would be seamless for companies that have an EMS system in place.

To strengthen the initial view of EMS implementation, from the point of view of a battery and consumer electronics manufacturing company involved in a longer supply chain, the Portuguese division of Bosch represents the analysis' subject. The environmental statement published in the EMAS registry represents a detailed and broad example of the data Bosch keeps track of: production emissions, energy, water and land usage [4]. The EMS system is perpetually reviewed and evaluated by management in terms of suitability, operation and performance evaluations, aided by employee contribution and and external communication [4]. The statement contains overviews for improving handling of hazardous and non-hazardous waste, use of packaging and energy consumption, where environmental impact, risk and opportunities are taken into account. The resulting action plans are drivers for policy creation and implementation [4]. Even indirect environmental aspects are put under scrutiny, with logistics, external companies and stakeholders along the supply chain are kept in check [4]. As a result, communication with suppliers outside Europe and programs with local suppliers leads to ever-more sustainable supply chain practices. The Environmental Report contains a substantial amount of detail in terms of objectives and achievements related to energy consumption (target: efficiency >= 1376 MWh, achieved: reduction of >= 1836 GWh), waste (target: 0.43 kg/ unit produced equivalent) and dangerous waste production (target: 0.007 kg/ unit produced equivalent), water consumption (target: 0.010 cubic meters/ unit produced equivalent, achieved: 0.008 cubic meters/ unit produced equivalent), alongside the ISO 14001:2015 certification and several plans, measures, investments and reports regarding the company's environmental implication [4].

In light of all these examples of detailed reporting and extensive use of EMSs, two potential obstacles can be highlighted: first, data granularity, type and reporting standards should be consistent between companies operating in the same sector, issue which the CSRD hopes to alleviate [22]. Second, however, is an issue which will be highlighted in this thesis and further discussed in future research: increased reporting is not necessarily directly proportional to increased environmental performance, so there is a clear gap between what companies report and what they do [13]. The analysis performed on Europol's and Bosch's Portugal EMAS Environmental Statement, alongside information acquired from Steger's work point to the fact that any company, regardless of a EMAS or ISO 14001 certified EMS or a company-specific one, with the details gathered through the processes indicated by an EMS, should be able to comply with DPP information requirements.

5.1 EMSs as solution towards CSRD targets

Even though the CSRD does not explicitly mention the usage of EMSs in the overall process of sustainability accounting and reporting that the European Parliament it is trying to standardize across the EU, a look at how EMSs can contribute towards the aims of CSRD may help solidify a case for their inclusion in this standardization and generalization process. The time-bounded sustainability targets and companies' progress towards their accomplishment has to be based on conclusive scientific evidence where appropriate; alongside a focus on the due diligence processes and impact represent an important step towards the generalization of sustainability reporting [22]. Just as well, the required publishing of the sustainability reports, aided by the amendments to existing regulations to integrate sustainability reporting requirements [22] will further contribute towards the standardization and integrity of sustainable business practices.

In order to achieve the goals of transparency, due diligence and integration in business models, companies have to organize leadership as best as possible. Fortunately, EMS are precisely promoters of such processes: they have guidelines that point towards the transparent communication with stakeholders, a focus on implementing policies aimed towards better organization that in turn improves efficiency from an environmental point of view. The policy-making capabilities of EMSs that lead to better record keeping and increased accountability 'match' the trajectory that the European Parliament is taking with the CSRD. As such, it seems like the CSRD, EMSs and DPPs could form an interdependent triangle: the CSRD targets can be achieved through widespread implementation of EMSs; the resulting final product of EMS implementation that will enable large scale sustainable, circular economy practices- DPPs.

5.2 EMS capabilities mapped to DPP information requirements

The benefits of digitalization in supply chains include availability and transparency of information, optimization of supply chain processes, collection of real time data, reduction of waste in processes, and enhanced inventory management [32]. DPPs' challenge in the manufacturing sectors can be put down to the inconsistent environmental information made available from suppliers and the lack of a digital reporting structure across the supply chain. In this context, the role that EMSs can assume in manufacturing and supply chain management may be beneficial towards DPP adoption.

Supply Chain Management (SCM) can be defined as the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities with the purpose of synchronising supply and demand through information and coordination mechanisms [27]. Until recently, companies have mainly focused on the reporting and reduction of direct emissions from their own operations (Scope 1) and those generated from purchased electricity (Scope 2). However, the need to accelerate reductions of GHG emissions in response to the climate crisis has led to an increased focus on those emissions generated from corporations' supply chains—Scope 3 emissions [8]. Scope 3 emissions account for as much as three-quarters of total emissions and are reportedly more than 11 times higher, on average, than direct operating emissions [8].

As per Weisner et al. [35], green material purchasing (alongside product design and manufacturing practices) is crucial for sustainable manufacturing supply chains. This involves raw materials, parts, and all supplies contributing to the final product. To facilitate the measurement of environmental and social footprints of products and manufacturing processes, companies can use life cycle assessment tools such as the aforementioned OpenLCA [15] to analyse their impact across their supply chain. Based on the life cycle analysis (focusing on battery companies), costs (environmental or of financial nature) induced by raw material purchasing, and analysis of manufacturing practices and impacts, companies can establish policies that can achieve set targets, with the help of EMSs. In turn, identified information as an outcome of this process can be linked to the following DPP information requirements: battery identification, type, chemistry (composition and hazardous substances), minimum recycled content. By accounting for the total carbon footprint of the entirety of the operation, an estimation of total carbon footprints linked to the production of one batch (and further divided per product from a batch) can be formulated. Such level of carbon footprint accounting can be established via Stage 1 and Stage 2 analyses performed by the company in question, and Stage 3 performed in collaboration with supply chain stakeholders and/ or the BigMile tool. With the continuous implementation of life cycle assessments, goals and policies helping to achieve lower emissions per product can be put in place.

A gap highlighted in related research that is closely connected in the aforementioned process (from EMS to DPP) is the incentive, motivation and transparency of third parties in the supply chain (i.e. raw material suppliers, part suppliers and different stage manufacturers) [35]. The following chapter will address this gap and perform an analysis from the lens of an EMS implementation in the supply chain processes. Regulatory obligations of disclosing relevant environmental details, operative emissions thresholds or a larger adoption of ISO 14001 or EMAS alongside the supply chain could help bridge this gap. The capability of certified EMS companies to be encouraging towards internal audits can be also repurposed for the implementation of EMSs in the Quality Control/ Assurance processes that take place during manufacturing. This could constitute the specific process in which companies could start with when implementing EMSs in their manufacturing activities. The frameworks that support record keeping can encourage enhanced stakeholder dialogue along the supply chain; this would benefit Stage 3 analysis and further improve life cycle analysis, future environmental policies and plans of action. The establishment of a tiered accessibility system to DPP information would ensure no conflict of interest between value chain stakeholders, privacy and the possibility of external audits from authorities.

The recycling, repair and refurbishment process would greatly be aided by EMSs and implicitly by DPPs. Once a product requires repairing or refurbishing, the responsible parties would assess the current product use lifetime emissions that would be updated inside the product's DPP, update the renewed parts and document their serial number, procedure and responsible employee. At the end of lifetime stage of the product, recycling companies can, based on their EMS and the handled product's DPP, document the recovered, recycled and rare metal content of products, document the process of discarding non-recyclable materials and account for the emissions produced by the transport, processing and discarding. If the recycling company has a certified EMS, the extended documentation and enhanced ability to communicate to external stakeholders will make the DPP updating process and the internal documenting process considerably friction-less.

6 PROPOSAL

In order to facilitate a transition from an EMS' capabilities to DPP information requirements, we made analysis into current information reporting structure; on this basis, we proposed the following guidelines for manufacturers willing to incorporate their EMS in the manufacturing process.

6.1 Status quo and the inclusion of EMSs as a catalyst

As a continuation of Weisner et al. [35] research of "Reference Architecture for DPPs at Batch Level to Support Manufacturing Supply Chains", this section aims to reexamine the manufacturing supply chain interactions and recognise where the implementation of an EMS support data acquisition for DPP within the material flow process. To start, we focus on the analysis made by Weisner et al. on the current flow of materials [35].

Material Flow covers the different steps material goes through until it becomes part of the final product [35]. Deliveries can comprise raw materials or components that need to go through one or more manufacturing steps at the plant first (i.e. for instance heat treatment or different steel cutting procedures) before being assembled into the final product [35]. Additionally, deliveries can also contain ready-made components that go directly in the product, subject to a quality control check [35]. Further on, components move through the plant into smaller batches, starting from batches on palettes to smaller handling units. Subsequently, materials are either batch-processed through different machining stages and then repacked into smaller handling units for transportation to assembly lines; or materials move directly into warehousing and repacking. Once at the assembly line, components are assembled into the final product, which is then stored in the warehouse before being shipped to distribution centres [35].

An issue highlighted by Weisner et al. [35] was the handling of faulty batches. The analysis of the As-Is Flow of Materials process and supporting IT systems performed by Weisner et al. 1 shows the manufacturing process from the Incoming of Goods until Outgoing of Goods and Distribution; in this section, we aim to improve the traceability and batch handling, alongside general sustainability and environmental reporting by analysing how EMSs can be integrated in this process.

Given that EMSs can be used for several purposes (e.g. raw material sources tracking, production methods, environmental impact) by most of the processes described by Weisner et al. (Figure 1) in the As-Is Material Flow, the decision has been to consider the case of EMS integration at the point of receiving the Incoming Goods and Incoming Quality Control stage. The reasoning for this decision is that, from that process stage onwards, production can take different courses; accounting before any ramifications in the process can provide the most accurate reporting of individual parts, batches, and the resulting product using parts from different batches, all accounted for in these two processes. Standard procedures in the context of this stage include material inspection, inventory management, process monitoring, final product inspection and continuous improvement [21][33]. The thesis' proposal of enhancement and inclusion of an EMS in the material flow process is shown in Figure 2.

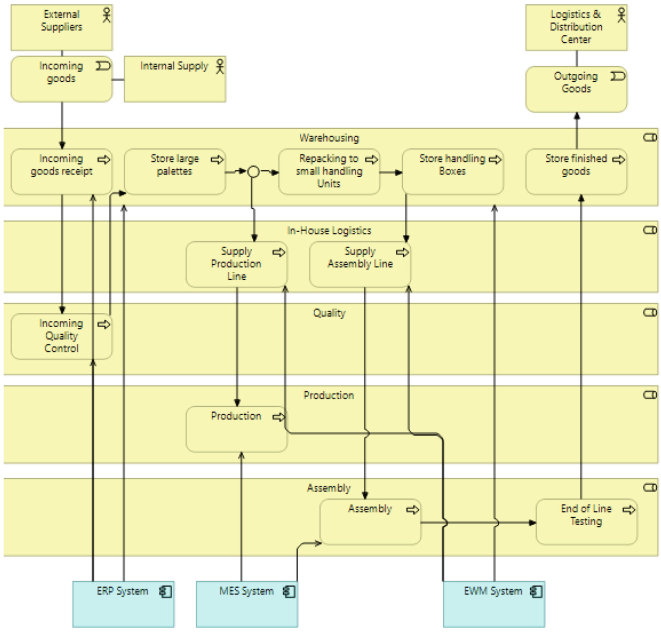

Fig. 1. As-Is Flow of Materials process and supporting IT systems modeled by Weisner et al.[35]

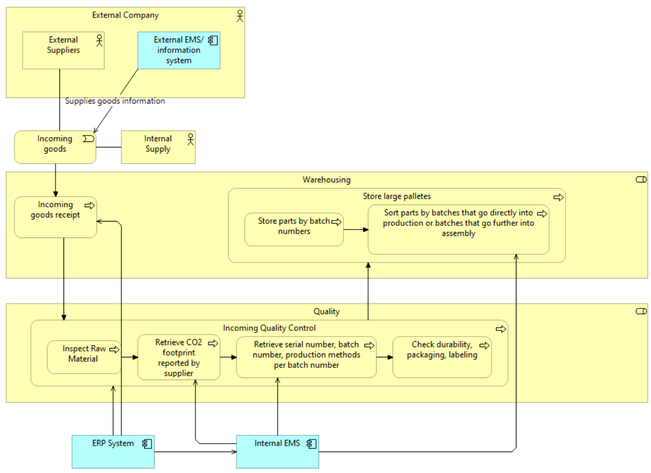

Fig. 2. Proposal of enhanced Flow of Materials process and supporting IT systems

As Weisner et al. point out, batch tracking is still an issue, and its solution is impeded because of a difference in cases: safety-critical products are likely to already benefit from an internal item/ batch tracking system [35]. However, for less critical products, such a system may not be cost-effective, with reports being mostly constructed by personnel by gathering data and timestamps[35]. All these circumstances mean that RFID-based batch tracking systems are not often implemented. This proposal is not a direct replacement or solution to the RFID batch tracking issue, but it can serve as a starting point for companies that already have an EMS system in place to be able to manage batch tracking. In collaboration with the ERP system, an EMS can help with batch tracking, as well as tracking operational emissions, production methods, and material usage. The efficiency of this proposed system is only improved when suppliers along the supply chain make use of EMSs, with data gathered during operations that can be forwarded further down the chain alongside the products supplied. Achievement of such a level of synchronization and data consistency along the supply chain has the potential to hit "two birds with one stone": improved sustainability reporting with quantitative data that can lead towards effective policy-making and a basic system of batch tracking which can lead towards fixing and improving products at a lower cost.

6.2 Recommended Guidelines

The following set of guidelines has been proposed as a result of the analysis of the Material Flow process and the implementation of an EMS in the aforementioned process:

(1) **Information Processing System**
- Information Communication Protocol
  Each stakeholder in the supply chain should be able to transmit information about the supplied product. An implementation of EMS throughout the supply chain would be ideal, but the transfer of data related to raw materials, CO_2 footprints, and production means, besides batch and serial numbers, in a standardized format and granularity (fitting the ESRS) should be put in place (as suggested by the CSRD [22]). A fictional example of data provided with supplied materials that is ESRS compliant is present in Appendix B.
- Due Diligence Process
  A communication system should be put in place along the value chain, with (internal) policies and action plans put in place that encourage timely supplier audits. As such, continuous improvement regarding data integration and sustainability goals can be achieved more efficiently. Tools such as OpenLCA (Figure 3) aid the audit process by assessing life cycle performance, evaluating performance, and establishing a clear path towards improved environmental impact; for companies that include long-distance shipping in their supply chain, BigMile [28] can help calculate transport emissions and promote collaboration between shippers and manufacturers towards improvement of efficiency.

(2) **Warehouse Practices Optimization**
For EMS to be able to provide the desired impact in regards to batch tracking and improved sustainability tracking throughout the manufacturing operations, the storage and sorting must be optimized and improved such that they fit the EMS capabilities; for warehouse management systems without RFID capabilities, based on the proposal, supplied parts and materials should be stored in accordance to batch numbers. Further on the production process, at assembly, batches of parts should be grouped such that a batch of final production products should be traceable back to the initial batches of composing parts. This may require an overhaul in operations, storage, and handling policies, as well as consistency in the data integration process. As this is not a direct replacement for RFID tracking systems, it can provide a starting solution to companies without requiring a sizeable investment into changing manufacturing tracking infrastructure. As RFID systems can take a minimum of 1500 US dollars and rise exponentially depending on needs, management software, maintenance, and scale [16], this starting solution would not involve a direct monetary cost, just a restructuring of operations. An example has been provided in Appendix C.2.

(3) **Meaningful Management**
An important point to highlight after the analysis of the EMS implementation and general environmental reporting of several companies, improving (environmental) reporting is not necessarily directly correlated to improved environmental performance. As noted by Andrew Gordon, Leader of EY Forensic and Integrity Services in his EY Integrity Report [13], corporate misconduct is rising, even if integrity standards are improving. With the “say-do” gap reported as an issue as far back as 2022 [13], not much seems to have improved in these terms. Irrespective of the implementation of systems that seek to improve business sustainability, the audit policies established by EMSs should be used to ensure responsibility and accountability of the corporate hierarchy. Proactive and transparent management should be a priority to ensure a real corporate environmental impact.

7 CASE STUDY

This section looks at how Omicron, an electrical power supply solutions company based in Austria, can use the proposed set of guidelines to improve its manufacturing process, more specifically the Material Flow process. This aims to provide validation through an analysis that can serve as an example for future implementation.

According to Omicron’s latest published environmental statement [12], the operational structure of the company contains a Receipt and storage of goods department, an Organization and administration department, and a Development department among others. As the environmental report does not directly refer to emissions produced during production and storage, a first suggested improvement would be the integration of all these departments in order to achieve higher cohesion. The administration department should create a system in which, in collaboration with suppliers, relevant environmental data described in this paper’s proposal should be integrated at the moment supplies reach the Receipt and storage of goods department. For the development of hardware solutions, in case of a lack of an RFID-based system, the storage of goods should be handled in such a way that the transition of parts to other developmental stages should be traceable. An example of such a (scaleable) process has been provided in Appendix C.2. This way, every final hardware product could be identified by the batches of its components, in case of a repair/ refurbishment process. Besides, each product’s production emissions could be closely monitored and accounted for, by including received supplier data and accounting for the emissions generated by the operational processes.

8 DISCUSSION AND FUTURE RESEARCH

The importance of the environmental action taken in the near future has driven researchers from a multitude of domains to work together on multiple fronts toward achieving the long-term objective on which humanity is reliant. This thesis' scope was to propose a first step in which the research towards DPPs can be expanded, by exploring how EMSs can serve as a starting point towards DPP consolidation in day-to-day manufacturing practices. The DPP information requirements serve as the base from which the proposal of the thesis handles the data integration process. The proposal itself analyses the strengths and capabilities of EMSs and creates a system that can both serve as a starting point for DPP implementation, as well as contribute towards emissions reporting.

One of the limitations of this research is the time constraint, stemming from the depth of information related to open problems posed by the implementations of DPP; during the literature review process, the focus of the research has shifted. Another limitation is linked to the lack of concrete information about different types of processes of companies, as they are either not made public or their description lacks specifics.

Even with this paper's research, assessments and proposal into the EMS and DPP fields, questions still arise. Future research recommendations are the following: firstly, an analysis of the energy and resource utilization of the DPP infrastructure, as well as an overview of its running costs in comparison to the estimated emissions efficiency. Secondly, an analysis of methods of data integration and transparency across the supply chain would be an important next step. The results of such research would contribute toward DPP integration, data standardization across the supply chain with minimal stakeholder friction, and accurate sustainability reporting that can further drive positive change.

A AI AND TOOL USAGE

For the analysis of the Bosch Portugal's Environmental Statement, the translation tool DeepL has been used (the original document was in Portuguese). For the analysed sections, the translation has been double-checked to ensure no discrepancies.

The ESRS example data provided in Appendix C.2 has been compiled partly by using ChatGPT, having been double-checked manually to comply with the ESRS.

Grammarly has been used for proofreading and double checking grammar, expression and sentence structure.

Archi.tool has been used for diagram construction (Figure 2 and Figure 4).

B EXAMPLE ESRS COMPLIANT SUPPLIED DATA


```
{
  "supplier_info": {
    "supplier_name": "EcoMaterials Ltd.",
    "supplier_id": "SUP123456",
    "contact_person": "John Doe",
    "contact_email": "john.doe@ecomaterials.com"
  },
  "shipments": [
    {
      "shipment_id": "SHIP789012",
      "date": "2024-06-29",
      "items": [
        {
          "batch_number": "BATCH001",
          "serial_number": "SN123456789",
          "raw_material": {
            "material_name": "Recycled Steel",
            "material_id": "RM1001",
            "quantity": "1000 kg",
            "source": "Post-consumer waste",
            "certifications": ["ISO 14021"]
          },
          "production_means": {
            "process_name": "Electric Arc Furnace",
            "process_id": "PROC3001",
            "energy_source": "Renewable Energy",
            "energy_consumption": "500 kWh"
          },
          "environmental_impact": {
            "CO2_footprint": "0.5 kg CO2/kg",
            "water_usage": "100 liters/kg",
            "waste_generation": "0.1 kg waste/kg"
          }
        },
        {
          "batch_number": "BATCH002",
          "serial_number": "SN987654321",
          "raw_material": {
            "material_name": "Organic Cotton",
            "material_id": "RM2001",
            "quantity": "500 kg",
            "source": "Certified Organic Farms",
            "certifications": ["GOTS", "OEKO-TEX Standard 100"]
          },
          "production_means": {
            "process_name": "Mechanical Processing",
            "process_id": "PROC4001",
            "energy_source": "Solar Power",
            "energy_consumption": "200 kWh"
          },
          "environmental_impact": {
            "CO2_footprint": "0.2 kg CO2/kg",
            "water_usage": "500 liters/kg",
            "waste_generation": "0.05 kg waste/kg"
          }
        }
      ]
    }
  ]
}
```


C AUXILIARY FIGURES

C.1 OpenLCA overview

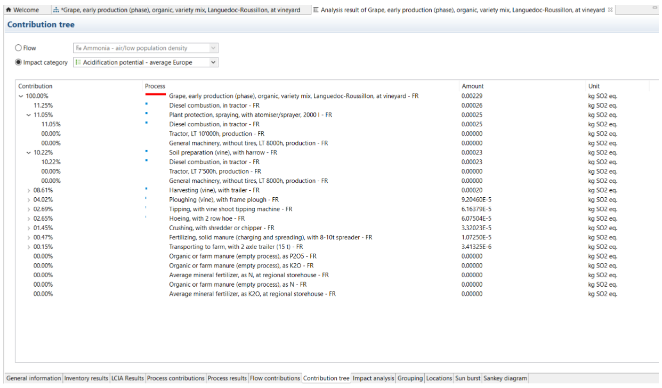

Fig. 3. Screenshot of OpenLCA software [15]

C.2 Batch Tracking Starter Solution

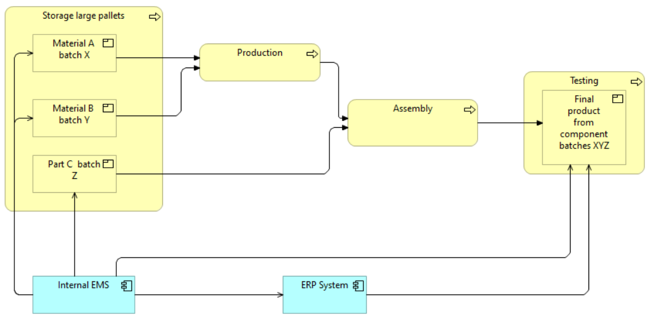

Fig. 4. Sorting and Storage concept proposal that enables batch tracking

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