Towards a Methodology for Analyzing Sustainability Standards using the Zachman Framework

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Abstract

There exists a multitude of standards and regulations related to sustainability. It is critical to enable users to identify applicable standards across entire lifecycles of products, processes, and services. To synthesize this variety of standards, it is important to analyze them from the information modeling point of view, while incorporating the requirements of various stakeholders. Here, we propose such a multi-perspective approach based on the Zachman framework. Using this approach it is possible to identify gaps and overlaps between, harmonize, and develop implementation strategies for sustainability standards. We then introduce our case study results as part of the Sustainability Standards Portal.

Keywords:

Sustainability standards, Zachman framework, environmental impact, sustainable manufacturing

1 INTRODUCTION

"Sustainability" is a term commonly used to express the capability to use a resource without permanently depleting it, thus preserving the resource for future use. The popular definition of sustainability comes from the World Commission on Environment and Development (WCED), which express sustainability in terms of a development, "..*that meets the needs of the present without compromising the ability of future generations to meet their own needs* [1]." Sustainability, according to the US National Research Council, is "*the level of human consumption and activity, which can continue into the foreseeable future, so that the systems that provide goods and services to the humans persists indefinitely* [2]". Though there are a multitude of definitions that address various aspects of sustainability, as Sitarz [3] interestingly observed, "In the final analysis however, agreeing on a formal definition of the term is not as important as coming to agreement on a vision of a sustainable world."

Standards play a critical role in enabling the sustainability of products, processes, and services. The American National Standards Institute (ANSI) [4] states that "*Standards are critical to establishing and maintaining a business and a strong economy."* According to standards.gov [5], standards are "Common and repeated use of rules, conditions, guidelines or characteristics for products or related processes and production methods, and related management systems practices." Therefore, a standard is an agreed, repeatable way of doing something. Regulations or governmental regulations, also called rules, "*specify mandatory (legal) requirements that (1) must be met under specific laws and (2) implement general agency objectives [5].*"

It is our view that standards and regulations will play a crucial role in mitigating the complexity of the activities and interactions required to create a sustainable world. The adoption of sustainability standards as best practices will aid in the reduction of the environmental impact of products (e.g., usage, recycling, end-of-life), processes (e.g., manufacturing, supply chain, production), and services. Despite their noble intentions, the increasingly large number of voluntary and regulatory standards related to sustainability makes it difficult to select and study the relevant suitable standards associated with a product line. In addition to this, many of the standards are defined within extensive documentation and therefore are difficult to interpret from the information modeling and implementation points of view.

From our interactions with industry, academia, and standards bodies, we have found that to comprehensively understand standards and regulations, it is important to analyze them from different perspectives. For instance, the information requirements of a manufacturer trying to comply with a regulation will be different from the information requirements of a regulatory body (standards and regulations will henceforth be treated synonymously and collectively referred to as 'standards'). In this paper, we propose a methodology for the analysis of these standards using the Zachman framework, taking into account the multiple perspectives of various stakeholders with the understanding that their goals may vary.

Different stakeholders may face similar and additional concerns regarding sustainability standards. These "stakeholders" consist of those parties to whom the standards may be relevant or of interest, and may include such groups as manufacturers, software developers, government employees, or end users. Even when standards are not directly applicable, their indirect effects quickly become relevant if a company wishes to do business in certain geographical locations. For industries with geographically distributed operations, the myriad of standards present a significant challenge.

The results of this study were implemented as a central component of the publically available Sustainability Standards Web Portal [6]. The paper is structured as follows: In Section 2, we describe the status quo, the problems with existing sustainability standards and common inquiries into these standards. In Section 3, we discuss our approach to address the above issues and the reasoning behind it. In Section 4, we provide insight into the Zachman framework and some specific application domains where this framework was used. In Section 5, we describe the analysis of sustainability standards based on stakeholder perspectives, and in Section 6 we describe the technical analysis of standards using the Zachman framework. In Section 7, we provide a case study describing how our approach is used, and finish with conclusions and ideas for future work.

2 STAKEHOLDERS VIEW OF SUSTAINABILITY STANDARDS

To achieve sustainability, products, processes, and services should meet the challenges not only related to traditional design issues such as functions and performance, but also environmental and social issues. This paradigm shift requires manufacturers, who have traditionally aimed at minimizing capital and maximizing profits, to aim at minimizing resources and maximizing value to society at large. Companies interested in developing sustainable products should be sensitive to sustainability related standards, design methodologies, and manufacturing techniques and tools.

For many small and medium enterprises (SMEs), it is difficult to identify and comply with the standards applicable to the products that they manufacture due to the limited resources (personnel or capital) available to invest in standards compliance. This is compounded by the fact that many of these standards are updated frequently, therefore requiring recurring investments. Some of the questions SMEs may ask are: Why should we follow this standard? Who developed this standard? How do we get a product certified as compliant to a standard? Who is the certifying agency? How long does it take to get certified? Such questions often come with no simple answers, and the answers require valuable time and resources to acquire.

To address these questions and issues, we need to create a structured methodology for understanding standards that is repeatable for a variety of standards and regulations, and a clear way of disseminating the information to the different stakeholders. The specific aims of this work are to provide the following:

i. Create a comprehensive understanding of standards that are related to sustainability by providing an overview, analysis, and other details for each standard.
ii. Help identify which are the applicable standards and implementation strategies for different stakeholders of these standards such as customers (users), industries (producers), government (implementers), software developers (support providers), researchers (support developers), and standard developers (developers).

3 TOWARDS A COMPREHENSIVE UNDERSTANDING OF SUSTAINABILITY STANDARDS

There are many factors that contribute to sustainability, and all of them must be considered when measuring the sustainability performance of a company. Sustainable manufacturing "is a systems approach for the creation and distribution (supply chain) of innovative products and services that: minimizes resources …across the entire life cycle of products and services [7]." Ensuring sustainable manufacturing requires an integrated system of systems approach that spans technical, economic, ecological, and societal issues. Interactions within and across these levels are critical to the fundamental understanding of sustainable design and manufacturing. Tackling any one of the issues in isolation could result in an inadequate solution and unintended consequences. Figure 1 illustrates the diverse range of metrics, methods and tools that are required to satisfactorily measure sustainability performance. The first category, "What to measure?" is concerned with the specific metrics and indicators[1] that are used to measure various sustainability factors. These can be further classified into different levels, such as process level and product level. The second category, "How to measure?" is concerned with the process of measuring the metrics and indicators in different situations. It considers data availability, engineering and business tools, and measurement methods. The third category, "How to report?" addresses the methods of reporting the measured data, such as through globally accepted reporting formats. The final category, "How to verify/validate?" is concerned with verifying and validating the reported data. There is a complex interaction between the metrics, tools and standards involved in gauging the overall sustainability performance. This calls for a structured and detailed analysis for the better understanding of sustainability standards.

Given the diverse nature of sustainability concerns, and the many stakeholders involved, we found it necessary to consider the problem from different stakeholder perspectives. We used this perspective-oriented analysis as a means providing general observations of what the detailed technical analyses may entail. Our stakeholder approach takes these factors into account and offers a means for insight into these sustainability standards. The Zachman framework (described in Section 4) then offers a way to critically analyze a problem by separation of concerns. It helps us break down the issues into a number of distinct portions, so that finer issues may be addressed at various levels of detail. The proposed methodology for analyzing sustainability standards has three components:

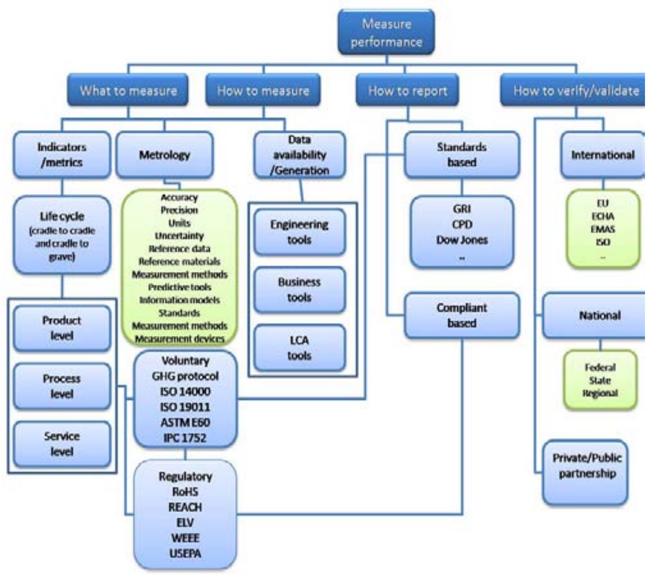

Figure 1: Measuring sustainability performance

1) *Analyzing the requirements of various stakeholders*

Information for a given sustainability standard is collected in this process from a variety of resources. The collected information is classified according to measurement performance views such as those seen in Figure 1. These metrics and indicators are defined for products, processes, and services across the entire life cycle (cradle to grave and cradle to cradle). The concerns of different stakeholders are then considered, by preparing comprehensive questionnaires about the standard from different perspectives. The questionnaires comprise the requirements of the standard for different stakeholders and should be answered by the detailed technical analysis. This will be explained further in Section 5.

[1] Measurement: A quantitative, physical attribute. Metric: A category that reflects a combination of individual measurements and that can be used to provide a large-scale view of a system and gauge system performance. It may be quantitative or qualitative. Indicator: A selected subset of metrics that is judged helpful for projecting future performance of a system [8].

Table 1: Zachman framework

	What (Data)	How (Function)	When (Time)	Who (People)	Where (Location)	Why (Motivation)
Scope (Contextual)	List of things	List of processes	List of events	List of organizations	List of locations	List of goals
Enterprise Model (Conceptual)	Semantic model	Business process model	Master schedule	Work flow model	Logistics network	Business plan
System Model (Logical)	Logical data model	Application architecture	Processing structure	Human interface architecture	Distributed system architecture	Business rule model
Technology Model (Physical)	Physical data model	System design	Control structure	Presentation architecture	Technology architecture	Rule design
Implementation (Detail)	Data definition	Programs	Timing definition	Security architecture	Network architecture	Rule specification
Functioning Enterprise	Usable data	Working function	Usable network	Functioning organization	Implemented schedule	Working strategy

2) *Technical analysis of standards using Zachman framework*

The sustainability standard is analyzed from the information modeling point of view. The Zachman framework is used to capture different aspects of a given sustainability standard. The collected information and knowledge about the sustainability standard are analyzed and organized according to the Zachman framework in this process. Each cell in the Zachman framework contains its meta-model, which describes what information should be captured and how to express it in the cell. Since meta-models of each cell describe different concerns, models in each cell can be revised without changing models in other cells.

3) *Integrating models in Zachman framework*

Models in each cell of the Zachman framework can exist independently, but this does not mean that these models do not have relationships with each other. Each model can be related to other models in the same column as well as in the same row. The composite or integration of all cell models in one row constitutes a complete model from the perspective of that row [9]. This statement derives from the fact that any one cell of one column is merely a single abstraction of reality. In Section 4.4, we explain how to harmonize and integrate the models in the Zachman framework.

4 AN APPROACH FOR ANALYZING SUSTAINABILITY STANDARDS USING THE ZACHMAN FRAMEWORK

Many sustainability standards have been developed and will be developed in the future. However, information models of these standards and the relationships among them are difficult to describe and understand because of their complexity. The Zachman framework can contribute to their understanding and describe complex relationships and information models in sustainability standards.

4.1 Introduction to the Zachman framework

The Zachman Framework [10] was designed to describe any idea that is complex to understand [11]. It is widely used for enterprise architecture modeling. It is depicted as a 6 x 6 matrix, as shown in Table 1, with cognitive primitives as columns and abstraction levels of information as rows. Each cell classifies enterprise information, and helps people to describe and understand the total enterprise architecture. The six cognitive primitives used in this framework are What, How, When, Who, Where, and Why. They are fundamental question primitives for communication, and integration of each question enables the comprehensive and composite description of the enterprise information.

The six rows in the matrix help to separate the problem into different levels of detail, with more detailed information being introduced in the lower levels. The top row describes the context of information, and is used to set up the domain of discourse. The second row is for domain experts to describe their business concepts. The third row describes system logics specialized from the second row, and the fourth row describes the technology applied to the system logics. The fifth row describes solutions that are actually implemented for the technology, and the bottom row denotes the operation of the enterprise.

Given its versatility, the Zachman framework has been used in the past to describe standards through categorization. In [12], the authors use the Zachman framework [13] to create 36 different characterizations to categorize healthcare and healthcare information system standards. In this scheme, each standard had a primary category based on its placement into one of the 36 cells. This serves as a useful way to group different standards using the Zachman framework, but does not provide the necessary insight into the standards themselves.

We propose the need for a more descriptive approach to provide information about standards to different stakeholders, most similar to that seen in Pnetto et al.'s work [14]. Here the authors are able to map the IEC 62264 [15] standards to the Zachman framework "*in order to make the framework as a guideline for applying the standard and for providing the key players in information systems design with a methodology to use the standard for traceability purposes*." We take this approach one step further by associating the Zachman analyses with stakeholder's perspectives, similar to what is presented through a security engineering application in [16]. In [16] the author uses the Zachman framework to describe the architecture for a cyber security system. The rows of the Zachman framework, which denote different abstraction levels, are mapped to different stakeholders such as consumer, designer, and builder. Though we have adopted a parallel approach, in our scenario, the different stakeholder viewpoints do not directly map to different levels of abstraction. For example, an industry observer might be interested in different aspects of a standard compared to a software solutions developer, but they need not be on different abstraction levels.

4.2 Analyzing the requirements of various stakeholders

In order to perform a Zachman framework based analysis, it is essential to define the domain of discourse precisely. Sustainability standards have a wide-ranging impact, which adds a level of complexity in establishing the domain of discourse. In order to properly analyze sustainability standards, we must identify the specific requirements of different stakeholders. Through our interactions with the industry, academia and other government bodies, we have identified a list of stakeholder groups based on the nature of information and support they require in dealing with sustainability standards. We call these *perspectives*, as the same individual may have different views of the same standard. The list of stakeholder perspectives we have identified includes the following: 1) Generic user, 2) Consumer or buyer, 3) Manufacturer or producer, 4) Government or regulatory agency, 5) Software solution provider, 6) Researcher, and 7) Standard developer. Our stakeholder's analysis approach is comprised of the following steps:

(i) Identify a set of perspectives from which stakeholders may view a standard

(ii) Identify a set of questions for each perspective, based on the question primitives of the Zachman framework

(iii) Provide a mechanism to answer these questions by synthesizing information from the detailed Zachman analysis of the standard

After identifying the most common stakeholder perspectives, we then identified concerns/issues based on the different cognitive primitives for each stakeholder. For instance, a software solution provider may be interested in the scalability and analytics of the data, while an industry stakeholder might be interested in how to become compliant and get certification.

We must note that for a given cognitive primitive, different stakeholders may have different concerns. For instance, if we consider the primitive "How," a consumer or buyer is mainly interested in: "How to verify that a product is standard compliant?" The answer to this question will include information such as logos and text annotations that can be found on compliant products. An industry user will be more interested in questions such as "how to become compliant and obtain certification?" This question is answered by giving information on certifying agencies and compliance guidelines for that standard. A government or regulatory body will be interested in how to regulate the standard and how to promote and support it. A software solutions provider will be interested in data availability (for example, design, manufacturing, material data), scalability issues of the standard (part, product, system, enterprise level data), and how this standard affects other related software. A researcher will be interested in how one can contribute to the development of the standard, and how to obtain statistics for its evaluation. Finally, a standard developer will be interested in how fast this standard needs to be developed, and how training can be provided for this standard. This representative set of questions illustrates the need to analyze standards from different perspectives in order to address the concerns of all the stakeholders involved.

The proposition and consideration of these issues/concerns lead to a set of terms and concepts that are used in the first row of the Zachman framework. Therefore, these questions play a crucial role in setting up the domain of discourse for further analysis. The information required for answering these questions is organized and obtained by performing a detailed technical analysis of the standard based on the Zachman framework, as described in the next section.

4.3 Technical analysis of standards using Zachman framework

In the Zachman framework, the columns Who, What, Where, When, Why and How can also be understood as people, data, network, time, motivation, and function, respectively. This synonymy allows for enterprise model associations to clearly be made with the "5 W's and an H." Similar synonymy exists for the rows, where the contextual, conceptual, logical, physical, and out-of-context can be directly associated with an enterprise's scope, business model, system model, technology model, and detailed representations, respectively. These associations provided additional guidance when using the Zachman framework to support our transition from questions from the stakeholder's perspective to answers through a technical analysis.

To better explain how the Zachman framework can be used in the technical analysis of a sustainability standard, we will describe the analysis of RoHS (Restriction of Hazardous Substances Directive) [17]. When analyzing a subject matter with the Zachman framework, each cell of the 6x6 matrix should provide an extensive analysis for its designated subset of the problem. Subsequently, it is important to acknowledge that this analysis can begin from any position of the 6x6 matrix due to the independence of each cell. Here we will initially concentrate on the first row, which will analyze the contextual aspect, or scope of RoHS.

In analyzing the contextual level, it was important to focus on what the objective was, to provide a scope for RoHS. In defining the scope, we defined the most abstract level of RoHS. This was vital to understanding when RoHS should be taken into consideration, and stresses the importance of the previous stakeholder analysis. As defined by Zachman, the information model in each cell in the contextual row is a list. These lists provide a high-level scope of the subject matter being analyzed.

In first defining 'What', we considered only physical entities associated with RoHS. This level of abstraction included the materials involved, the products considered, and the information involved. When identifying 'How', we took into consideration the *Supply-Chain Operations Reference* (SCOR) [18] model and identified the Source, Make and Deliver processes of the supply chain as processes where RoHS becomes pertinent. This high level definition of processes was intentional, so as not to narrow the scope to a point where the RoHS application becomes ill-defined and perspectives are overlooked, yet not broaden the scope to a point where the analysis loses its effectiveness. Continuing along the contextual level, the 'Where' aspect of Zachman defined which geographical areas RoHS is active. The 'How' aspect was used to identify the parties or organizations to which RoHS is critical. Parties identified included all stakeholders from which perspectives must be considered, including electronics manufacturers and suppliers, government agencies, and customers. The 'When' row was used to identify events that will initiate cycles. At the most abstract level, we defined these events as the buying and selling of electronic goods. The 'Why' was used to identify the high level goals of RoHS, namely reduce environmental contamination by limiting hazardous waste, and from the perspective of the manufacturer also to avoid penalties and improve brand image. The purpose of Directive 2002/95/EC (RoHS) on the restriction of the use of certain hazardous substances in electrical and electronic equipment is to approximate the laws of the EU Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment.

After a carefully executed analysis using the Zachman framework, the scope of RoHS was broken down, providing a transparent definition for all stakeholders involved. As the Zachman analysis progresses downward from row to row, the level of abstraction is reduced, as can be inferred from the row labels. To demonstrate these changes in levels of abstraction, let us consider the 'What' column. Recall at the highest level of abstraction, the contextual level, the 'What' column was used to provide the scope of what RoHS covers: the materials involved, the products involved, and the relevant information involved. The second, conceptual, row is used to define the "business model" used in RoHS. At this level of abstraction, a simple list is no longer used, instead a traditional "business entity-business relationship" model is employed. This level of abstraction provides some detail into how entities associated with RoHS interact. For instance a "product" is composed of an "assembly" which is composed of a "homogenous material[2]." As implied by its label, the second row allows for the conceptualization of interactions between entities through relationships, which can be considered the "semantic model." These business models differ based on the stakeholder perspective taken.

Progressing downward in the 6x6 matrix, the third row provides the logical data model. At this level of abstraction, elements which were once abstract concepts are now considered logical data models. This level of abstraction is where data entities and their relationships exist, where a data entity is a logical representation of an element from earlier levels of abstraction. Here is where an information model, including attributes, of what a "homogenous material" is, can be found. The fourth row is where the Physical Data model is located. This row is technology constrained, so where the third row provided the attributes of a "homogenous material," it is this row that describes how it is defined[3]. And finally the fifth row, or the detailed row, is where the data definition can be found. Where row 4 defines how a homogenous material should be defined, row 5 is where its actual definition can be found, for instance the composition of the solder used in an electronic product.

4.4 Integrating models in the Zachman framework

The Zachman framework was used to describe RoHS with thirty independent cells (we ignored the last row that denotes actual physical operations), each with content that can be modified without directly affecting the content of the other cells. Although each cell in Zachman framework can exist independently, it is useful to take them in context of one another. In fact, we found this a helpful means for promoting the continuity of the levels of abstraction between columns. For instance, consider the statement "RoHS applies to manufacturers who buy hazardous materials to produce electronic products in Europe." In this statement, we were able to tie together the 'who,' 'what', 'where,' 'when,' and 'how'" as it applies to RoHS, giving one particular piece of insight into the scope of RoHS. This same practice was repeated often when defining the "conceptual," "logical," "physical," and "detailed" rows for the Zachman analysis.

Figure 2 shows the integrated information model for describing a business scenario in which a company wishes to manufacture a product for sale in the European Union market. RoHS compliance is an important issue in this scenario. The model encapsulates the information requirements that will allow the company to place a compliant product in the market. The information model can be likened to sentences describing a business scenario that spans the different columns of the Zachman framework. For instance, a *Supplier* could *Produce* a Component that a *Final Producer* may *Assemble* in a *Product* that is to be sold in the *European Union*. The italicized words in this sentence are conceptual elements that are modeled in the integrated information model. It is easy to see that the individual concepts, decisions and processes listed in the figure can be traced to the various cells of the Zachman framework. For instance, "what" types of components belong to this scenario is given by the conceptual and contextual layers (rows 1 and 2) of the "what" column in the framework. The types of manufacturing processes for these components is given by the conceptual layer (row 1) of the "how" column of the framework. The nature of the manufacturing processes that can affect RoHS compliance is given by the logical and physical layers (rows 3 and 4) of the "how" column of the framework. The time point of the component test is given by the "when" column of the framework. Having performed the detailed technical analysis of RoHS using the Zachman framework, we integrate the models to describe the business scenario in complete detail.

5 AN EXAMPLE TO DEVELOP AN IMPLEMENTATION STRATEGY FOR COMPLIANT CONFORMANCE

The steps required to implement a standard depend on the stakeholder and implementation need. To explain this implementation process, for instance, let us assume that a product manufacturer in the US is interested in having a product (e.g., hair dryer) RoHS compliant certified. This section breaks this certification into a three step process. In each step, we will discuss how our approach will assist RoHS certification.

In this section we will also introduce our Sustainability Standards Portal (SSP) [6] as a means for referencing information in determining RoHS compliance. This online web portal has been developed at NIST to serve as an unbiased source for information pertaining to sustainability standards. This information also includes detained stakeholder and technical analyses of selected sustainability standards. The information infrastructure provided will provide valuable guidelines to develop such in-house certification procedure initiatives, avoiding costly consulting fees. An example of how our approach can provide these guidelines is given below.

Step 1. Acquisition of Knowledge: In this step, the manufacturer is interested in gathering information about the Standard/Directive that is affecting the export of a product or a service. Some of the questions the manufacturer might ask are: What is RoHS? Why get RoHS certified? What product to get RoHS certified? Who would certify? How it is certified? **Support:** The manufacturer can acquire answers to these questions through our stakeholders' analysis approach. A RoHS-based version of this approach has been implemented in the SSP.

Step 2. Analysis of business and manufacturing procedures: In this step the manufacturer needs to analyze different business processes within the company and model them. **Support:** The manufacturer would adopt our technical analysis approach of RoHS based on the Zachman framework. For instance, if the manufacturer wants to know who are the people responsible for making sure that a product has less than the specified amount of Lead (Pb) and what roles these people have, then the manufacturer would refer to the 'who' column of the Zachman analysis of RoHS.

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[2] "Homogeneous material" means a material of uniform composition throughout that cannot be mechanically disjointed into different materials, meaning that the materials cannot, in principle, be separated by mechanical actions such as unscrewing, cutting, crushing, grinding and abrasive processes.

[3] The maximum permitted concentrations are 0.1% or 1000 ppm (except for cadmium, which is limited to 0.01% or 100 ppm) by weight of homogeneous material. This means that the limits do not apply to the weight of the finished product, or even to a component, but to any single substance that could (theoretically) be separated mechanically.

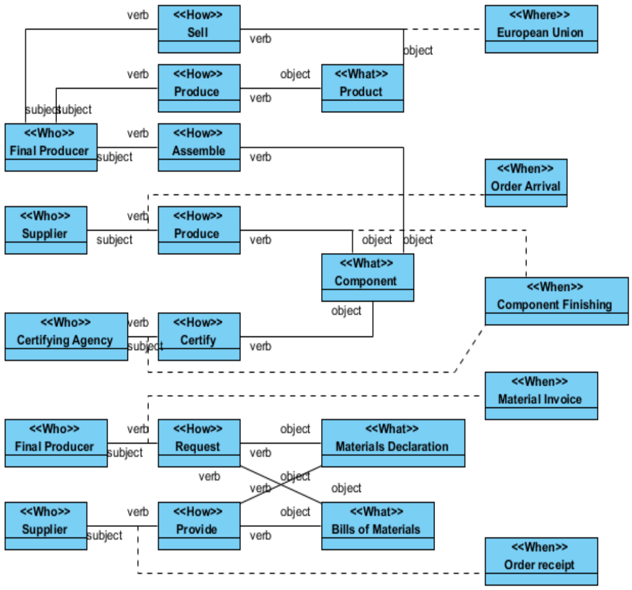

Figure 2: Business scenario: Manufacturing and selling RoHS compliant products

Step 3. Implement and verify: In this step, the manufacturer would develop actual implementation strategies in the form of steps to be followed to get the product RoHS compliant, implement them and verify the outcome through report and certification. **Support:** The manufacturer could refer to the information provided in the "who", "how" and "what" columns respectively to identify the certification agency, certification procedure followed and instruments used. While this will differ depending on needs, examples can be found in the SSP.

6 SUMMARY

Standards and regulations play a crucial role in realizing the vision of a sustainable world. However, if they are not clearly understood by all parties involved, these standards will fail. It is therefore important to critically analyze sustainability standards by considering different perspectives, and addressing the requirements of all stakeholders.

In this paper, we have described a rigorous and organized approach for analyzing and understanding sustainability standards. We first consider a given standard from the perspectives of different stakeholders, establishing a domain of discourse that takes into consideration the concerns of all parties involved. We then perform a detailed analysis of the standard using the Zachman framework, Once we have constructed this repository of information that addresses all the aspects of a standard at various levels of detail, we integrate the information to describe specific scenarios of interest to specific stakeholders. We believe that this organized and detailed approach is essential for sustainable practices in today's world, which brings together disparate parties with widely different concerns to the same table. Based on this study, we have also created thematic structures for promoting the fast understanding of standards, captured the essence of the performance issues related to sustainability, and created a primitive framework for querying a database of standards information, all of which are available publicly in the Sustainability Standards Landscape web portal. Our next step is to compare these standards to find gaps and overlaps in their domains of discourse.

7 DISCLAIMER

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