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Environmental Management Maturity: The Role of Dynamic Validation

Marta Ormazabal[1], Jose M. Sarriegi[1], Eliot Rich[2], Elisabeth Viles[1], and Jose J. Gonzalez[3]

Abstract

Maturity models enhance the performance of companies by prescribing a trajectory through stages of increasing capability. However, a recent review of maturity models concludes that current maturity models hardly meet the design principles required for prescriptive use. To address this deficiency, we conducted semistructured interviews and a Group Model Building study with industrial companies in Spain in which we studied the progression toward a Leading Green Company as the highest maturity stage of environmental management. The findings from the study were tested using surveys with enterprises in Spain, Italy, and the United Kingdom, semistructured interviews in the United Kingdom and case studies in Spain. Using these data sources, we develop a causal model that captures an idealized environmental management maturity dynamic progression though stages. By mapping maturity stages to feedback loops connected to actions to improve those maturity levels, system dynamics can help companies articulate policies for transitioning toward higher maturity stages.

Keywords

maturity model, environmental management, capability models, dynamic modeling, maturity stages

Introduction

Sustainability transition is urgently needed, and it calls for systemic adoption of better environmental management (Delmas et al., 2019). Transition toward environmental sustainability requires change in operations, improved coordination of human and technical abilities, as well of resources (Aragón-Correa et al., 2008).

This transition may be described through maturity models. Maturity models, which have their origin in quality management, describe the characteristics of a process or an activity through a number of different performance stages, going from some initial stage to a more advance stage

[1]Universidad de Navarra, TECNUN Escuela de Ingenieros, Spain
[2]University at Albany, Albany, NY, USA
[3]University of Agder, Grimstad, Norway

Corresponding Author:
Marta Ormazabal, Universidad de Navarra, TECNUN Escuela de Ingenieros, Paseo Manuel Lardizabal 13, San Sebastián 20018, Spain.
Email: mormazabal@tecnun.es

(Fraser et al., 2003). Arguably, the first maturity model was proposed in 1979 by Crosby in the book "Quality is Free: The Art of Making Quality Certain" (Crosby, 1979). Crosby argues that good quality management principles more than pay for the cost of the quality system in terms of return on investment: "quality is free." To this effect, he proposes the quality management process maturity grid, which categorized best practices along five maturity stages and six measurement categories. In the same year, Nolan (1979) proposed a maturity model for data processing consisting of six stages of growth. Maturity models were quickly embraced by the software industry. Carnegie-Mellon's Software Engineering Institute established the benchmark capability maturity model targeting software development in 1993. Capability maturity model spawned a series of frameworks under the umbrella of the Capability Maturity Model Integration (CMMI®). Over time CMMI® evolved to encompass process improvement for product development (CCMI-DEV), service development (CCMI-S VC), acquisition of products and services (CCMI-ACQ), development of workforce capability (PCMM) and CMMI Data Management Maturity model (Pane & Sarno, 2015).

The case of environmental management was selected in this research owing to the increase concern of environmental management among companies (Céspedes Lorente & De Burgos Jiménez, 2004). The first author who came up with a classification model to describe the increasing importance of environmental concerns for business policy and strategy was Petulla (1987). Since then, many researchers have classified corporate responses to environmental management. Ormazabal and Sarriegi (2014) identify, based on literature review, the different types of environmental classifications among companies. Nevertheless, as thoroughly documented by Wendler (2012) for maturity models, these classifications do not explain in depth how a company can reach and surpass these stages. C. J. C. Jabbour (2010) concluded that these stages do not fully explain the environmental management evolution within organizations. A recent work on change management toward environmental sustainability (Wiesner et al., 2018) conducted an extensive literature review to detect gaps in change models. The main gap detected was the lack of a holistic change management model to "progress the environmental sustainability journey."

This study adds to the literature by simulating the expected behavior over time (BOT) of the indicators of a maturity model for environmental management in a hypothetical company. To do so, this study developed, on the basis of personal interviews, questionnaires, workshops, and case studies, an empirical model for managing change toward environmental sustainability in small and medium-sized enterprises. We advance the process by using techniques of system dynamics modeling to explicate and validate: The model contains explicit causal links, feedback structures, and anticipated behavior that we found consistent with the grounded expectations of a large group of expert informants. While the model is not completely endogenous, it serves to move the conversation toward structures and metrics that can be codified and integrated. In this way, we address a weakness of many maturity models, viz. lack of empirical validation (Wendler, 2012).

State of the Art

Wendler (2012) conducted a mapping study of the maturity modeling literature to date. A mapping study is an extended literature review for the specific purpose of identifying, analyzing, and structuring the goals, methods, and contents of a given topic (see, e.g., Kitchenham et al., 2011). Wendler reviewed various definitions for maturity model. He adopted the definition by Becker et al. (2009, p. 213): "A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired, or typical evolution path of these objects shaped as discrete stages. Typically, these objects are organizations or processes."

Wendler (2012) surveyed the use of maturity models through 2010, and identified articles in scientific journals and conferences on uses of maturity models in nearly two dozen application domains. Software development and software engineering were by far the most popular application areas with a total of 89 articles. Applications in public sector, project management, other business areas, engineering and knowledge management and process management appeared in more than 10 papers each. Other applications included engineering, outsourcing, medical sector, supply chain management, business functions, business intelligence, collaboration processes, finance/controlling, IT functions, IT governance, IT alignment, leadership, and sustainability (Wendler, 2012, Fig. 3, p. 1328).

Wendler defined several research questions for his mapping study. They included (1) in which domains are maturity model research applied? and (2) how are developed maturity models validated? As of 2010, maturity models had been applied in 22 domains (Wendler, 2012, Fig. 13, p. 1328). As to the second question (validation): Wendler's mapping study was particularly concerned with maturity models that satisfied the paradigm of design science (Hevner et al., 2004). Design science requires that artifacts, beyond being developed in terms of content and structure, should be validated. That is, the utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.

Among the 108 studies that concerned development of maturity models in Wendler's mapping study, less than half (42) were design-oriented and, with one exception, all were validated. In about half of the instances, the validation methods employed were case studies/action research, in about one-third surveys and the remainder were validated based on interviews/discussions.

We have conducted a literature study on maturity model studies published since 2011 to detect possible applications of maturity models on environmental management and to identify potential improvements in validation of maturity models. The table below is an overview of studies that have conducted validation studies. Notably, several of the studies extend the application domain of maturity models (viz. to cybersecurity in Critical Infrastructure, Safety, Electronic Government, and Environmental Management).

Table 1 extends Wendler's (2012) study with literature that appeared after 2010; they are relevant for our study because they concern validation of maturity models. Table 1 adds evidence that simulations models and methods have not been applied after Wendler's seminal study. Our study is the first to do so and for a good purpose, viz. to deliver a proof of concept of validation of maturity models using system dynamics methods.

This article addresses two of Wendler's observations about the lack of maturity in the study of maturity itself. He concluded that "many maturity models suffer from a lack of a proper validation of their structure and applicability and therefore of their usefulness" (Wendler, 2012, p. 1330). Indeed, Wendler found that the majority of academic publications did not include validation within their scope; in fairness to the authors, he included conference papers in his search data set, so there is a counterargument that the publications may not represent completed products.

A second, and subtler observation, is an apparent imbalance between descriptive and prescriptive works in the literature. Wendler notes that many of the articles in his collection describe and apply the maturity model concept to specific industrial contexts, sometimes idealized, sometimes buttressed with case studies, but leaving the applicability of possible models to the reader. Prescriptive models are less common, and he encourages researchers to advance the theoretic and empirical bases for maturity models through the principles of design science.

Examination of more recent works show that this gap has not been filled. Verrier et al. (2016) conclude their literature review of lean and green concepts with a CMMI-like maturity model that rests on five hierarchical stages. The model builds from an internal organizational state of limited knowledge to one where the measure and management of lean and green practices become an integral part of a firm's production model. Verrier's maturity model does not indicate processes or timings needed to incentivize migration to later stages. Farias et al.'s (2019) systematic review and framework for assessment of lean and green programs within a broad context of common management processes presents an opportunity for static evaluation of a multidimensional improvement effort, but recognizes the lack of contextual analysis.

A recent work by Henao et al. (2018) considers literature on the relationship between lean manufacturing and factors that influence its sustainability. They conclude that there are two conflicting

Table 1. Maturity Model Studies.

Application domain	Topic	Reference	Validation type
Software development/ engineering	Agility	Gren et al. (2015)	Statistical tests and empirical data
Cybersecurity	Critical infrastructure	Karabacak et al. (2016)	Conceptual model—no validation
Business intelligence	Application of data analytics in organizations	Lismont et al. (2017)	Survey/expert validation
	Implementation of electronic health records	Brooks et al. (2015)	Case study
Engineering	Design automation	Willner et al. (2016)	Expert validation
Electronic government	Open Government/Social media	Lee and Kwak (2012)	Expert validation
Energy management	Linking ISO 50001 processes and CMMI	Jovanović and Filipović (2016)	Self-assessment in ISO-certified and noncertified organizations
Environmental management	Natural resource management/ sustainability	Ngai et al. (2013)	Case study
	Environmentally conscious design (eco-design)	Moultrie et al. (2016)	Case study
Manufacturing	Industry 4.0	Schumacher et al. (2016)	Case study
	Product development	Kandt et al. (2016)	Case study
	Supply chains	Mendes et al. (2016)	Expert validation
Lean and Green	Lean and Green manufacturing	Verrier et al. (2016)	Systematic literature review
	Lean and Green performance	Farias et al. (2019)	Systematic literature review and framework
Safety	Quantitative risk assessment	Rae et al. (2014)	Initial empirical validation of the maturity model's completeness, realism and appropriateness

threads, "one which supports complementary interactions between lean manufacturing and all three pillars of the triple bottom line, and the other, which evidences trade-offs among them" (Henao et al., 2018, p. 99). This inconsistency may be due to contingent variables that are not yet included in the analysis (Farias et al., 2019, also notes this gap). It is not uncommon to find such ambiguity in complex systems, where forces can sometimes work in concert and in other situations (or even in a stage of the same one) serve to work in apparent opposition as limits and constraints emerge.

Consequently, this study fills the following gaps: (1) It provides a causal model based on Group Model Building (GMB) and a reference mode. (2) It increase the validation methods with the inclusion of techniques derived from System Dynamics practice. (3) It advocates for the use of these techniques for expand our understanding of dynamics and the role of feedback when considering maturity models.

Implicit Feedback in Maturity Models

Why is the System Dynamics lens appropriate for review and validation of maturity models? A maturity model is by nature a process with rich dynamic structure. Rigon et al. (2014, p. 266), in their paper about information security maturity, introduce the objective of their paper this way: "This paper proposes a method for information systems management through a periodic evaluation of maturity and continuous improvement of controls." Fraser et al. (2003, p.1501), in their article about maturity of managing product development collaborations, state, "Successful alliance projects go through a sequence of interactive cycles of learning, re-evaluation and readjustment," which beyond referring to dynamics also to also hints at feedback. Plomp and Batenburg (2010, p. 232), in their article about chain digitization maturity, assert: "Earlier we referred to the accumulation assumption of maturity models, that is, when a certain level is achieved all lower levels need to be passed." Ramasubbu et al. (2005, p. 80), in their article about maturity model for leveraging global resources, state, " . . . evolutionary framework with 24 new key process areas essential for managing distributed software product development and continuously improving product management capabilities." Aneerav et al. (2007, p. 99), in their article about software project management maturity, posit: "The proposed Evolutionary Software Project Management Maturity Model (ESPM3) has three maturity levels and a continuous process improvement group of key process areas (KPAs)."

The literature also points at gaps and actions to close the gap, that is, balancing feedback, albeit without explicit reference of feedback. A recent article on a maturity model for information security states,

> After identifying critical processes and controls, the use of a maturity model allows the identification of gaps that represent risk and how to show them to management team. Based on this analysis, action plans can be evaluated and developed for the improvement of processes and controls considered deficient up to the desired development level. (Rigon et al., 2014, p. 267)

The Value of System Dynamics in Maturity Models

Herein is an opportunity for system dynamics to contribute to maturity model research. Process improvement was a key application area for system dynamics in the decade 1990-2000 (see Repenning & Sterman, 2001, for a core model and an overview of the work). A main contribution of the works was resolving the project improvement paradox: explaining the fact that process improvement programs lead to significant results in a minority of the cases reported in the literature. By extending the discussion of maturity models from metrics and descriptive activities to a dynamic model, we illuminate where both success and failure may lie.

We extend this stream of research below. Recall that an important aim of our study is the experts' view of the ideal trajectory of capability improvement following maturity stages. We demonstrate the use of GMB to increase the validity of theoretically derived maturity models as applied to environmental management. The GMB process allows us to generate a reference behavior for maturity indicators and posit a dynamic model, discussed below. We also expose the feedback structures implicit in maturity models, with the future opportunity to develop prescriptive considerations, such as the dynamic traps that limit adoption and process evolution (Repenning & Sterman, 2001, 2002), that dynamic simulation provides.

Method

As mentioned in the introduction, the objectives of this research concern a proof of concept that maturity models can be validated using system dynamics. To build the environmental management model, information was collected through different methods (Figure 1).

First, we carried out semistructured interviews among 19 Basque companies from different sectors such as chemical, automotive, railway, elevators, and electrical equipment. The qualitative interview is the most common and one of the most important data gathering tools

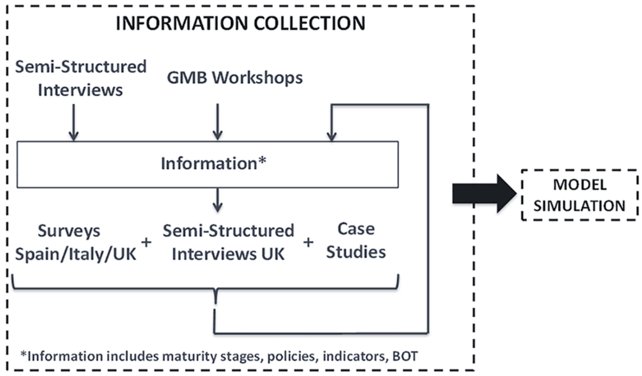

Figure 1. Research methods.

in qualitative research (Myers & Newman, 2007). The objective of these interviews was to understand how environmental management has been deployed in each enterprise and the consequent factors that affect environmental management. The average face-to-face interview lasted around 75 minutes. The questions were divided into three groups: company's initial situation, reasons and motives why good environmental practices are implemented, and how the environmental management is implemented and measured in each company. The interviews provided grounded source material for causal factors, accelerants, and barriers to process maturation. As the main factors the following ones can be highlighted: environmental legislation, environmental impact of the company, company green image, market share, process implementation, economic benefits, top management commitment, training of employees, and external communication on environmental issues. All these factors were necessary to create the structure of the environmental management maturity model.

Subsequently, we used two GMB workshops with six environmental experts to elicit the necessary tacit information (Andersen et al., 2007). GMB is a methodology for capturing information in collaboration with a group of people who are experts in the problem at hand (Vennix, 1996). It is a very suitable method to collect all the necessary information (Andersen et al., 2007). As Creswell and Miller (2000) state, credible data also come from close collaboration with participants throughout the process of research. The participants included environmental managers of different enterprises, environmental consultants and academics with experience in environmental projects. When collecting the information raised by the experts, the GMB methodology uses different exercises. The experts proceed to define the stakeholders involved in the environmental management, the policies that affect the evolution of the environmental management. These policies were subsequently ordered according to the temporal order in which they should be implemented in the companies. It was at this point that six groups of policies arose, and consequently six maturity stages. For each of these six stages, several indicators were identified and the experts graphed them over time to appreciate their evolution, constructing the BOT graphs (Ormazabal et al., 2017). Consequently, with all the information obtained from the semistructured interviews among Basque companies and the 2-day workshops, a first version of the Causal Loop Diagram that represented the structure of the environmental management evolution within companies was developed. The specific results and the process carried out in the surveys and GMB workshops are recorded elsewhere (Ormazabal & Sarriegi, 2012).

We improved and validated the collected information through an iterative process: several surveys, semistructured interviews and case studies were carried out with firms based in

Table 2. Size of Companies by Number of Employees.

Number of workers	Number of answers	Percentage
0-10	9	13
11-50	25	36
51-250	22	31
>250	14	20
Total	70	100

Table 3. Declared Market Size of Companies.

Market size	Number of answers	Percentage
Regional	9	13
National	25	36
International	36	51
Total	70	100

Spain, Italy, and the United Kingdom. Spain, Italy, and United Kingdom are the three states with the highest number of ISO 14001 certifications (i.e., addressing environmental management) in Europe (ISO 2011). This fact means that we can find more companies that have advanced along their maturity states and therefore can provide us with more information.

Based on online lists provided from the chambers of commerce of Italy and Spain, we sent an initial survey to 588 Italian and Spanish companies, obtaining a final sample of 70 firms, which corresponds to a global response rate of 12%.

Most respondents were exclusively environmental managers (45%), followed by those in charge of other tasks (30%) and general managers (25%). Company profile information in terms of company size and market size is presented in Tables 2 and Table 3.

The questionnaire had three parts. In the first part, the proposed maturity stages were defined and respondents were asked to order the different maturity stages in ascending evolutionary stages. The stages were ordered alphabetically (Figure 2) to avoid influencing respondents, and there was the option of marking some stages as parallels, deleting others, or adding additional ones for ranking.

In Table 4, the results of this part of the questionnaire are shown. The different stages of maturity were ordered over time according to the opinion of the respondents.

Legislation Fulfillment was the lowest stage, with 80% of respondents agreeing. Training became the second stage (36%). Systematization was chosen as the third stage (46%). The last stages were Ecological and Economic Benefits (ECO2; 34%), Eco-Innovation (66%) and Leading Green Company (76%).

Some of the answers were really clear, while others were a little more confusing. In the training stage, 36% agreed that this should be the second stage. However, 26% of respondents said this stage should be the first and 28% said it should be the third. On the other hand, respondents do not fully agree with the order of the ECO2 stage. Thirty percentage of the answers pointed to the third position, while 34% pointed to the fourth position. These two stages needed further study.

The second part of the questionnaire focused on activities and actions that take part in each maturity stage and the apparent intensity of their importance, taking into account the factors previously defined. The third part was to know if companies could position themselves in one of the mentioned maturity stages.

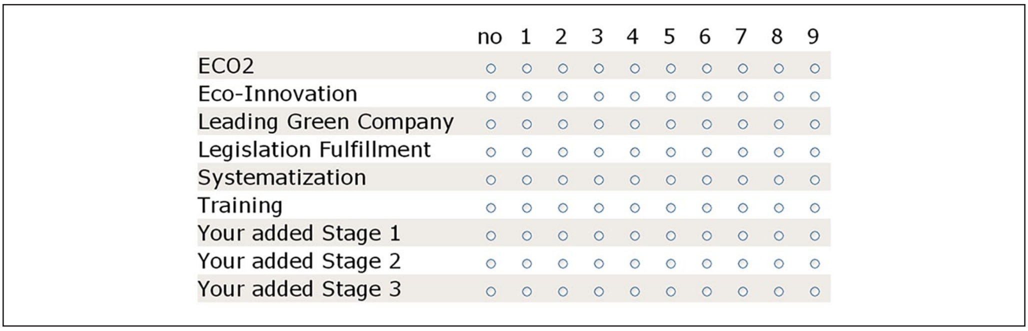

Figure 2. Maturity stages alphabetically arranged.

Table 4. Maturity Stages' Order.

	Position						
Maturity stage	1	2	3	4	5	6	Response rate
Legislation Fulfillment	80%	14%	6%	0%	0%	0%	100%
Training	26%	36%	28%	4%	2%	0%	96%
Systematization	6%	10%	46%	28%	4%	6%	100%
Ecological and Economic Benefits	8%	24%	30%	34%	0%	2%	98%
Eco-Innovation	0%	0%	6%	18%	66%	10%	100%
Leading Green Company	0%	0%	0%	4%	20%	76%	100%

The results of the survey indicated that the companies were not completely in agreement with the order of Training and this could be due to the fact that the name and meaning of the stages were not appropriate. Consequently, Legislation Fulfillment has been replaced by Legal Requirements. In this "new" stage, companies identify applicable requirements and implement end-of-line solutions to begin to reduce their impacts. On the other hand, Training has been replaced by Responsibility Assignment and Training; that is, in this second stage, companies must assign responsibilities to carry out the corresponding environmental measures, as well as provide technical training on the equipment implemented in the previous stage. In this way, after this second stage the legislation would be complied with. The other name that has been changed is Eco-Innovation, which has been replaced by Eco-Innovative Products and Services. The main objective of this change is to clarify that at this stage companies are beginning to focus on their products and services but not so much on their processes, as they have been improving their processes since the systematization stage.

A second survey was sent to ascertain whether U.K. corporate representatives agreed with the information previously obtained and to find evidence that support the theory. The U.K. companies were randomly selected among LinkedIn environmental groups. The questionnaire had to be completed online and the link of the questionnaire was sent to 273 corporate practitioners, obtaining a total of 55 answers that corresponds to a response rate of 20.2%. The survey had several questions. The first one was focused on the companies' environmental management evolution. First, companies were asked if they agreed with the maturity stages' order. The second question was to identify in which of the stages they currently were and the third one was to identify if they have passed through all the previous stages until reaching the previous stage. The fourth question was about the factors that have been important for the evolution of the environmental management in their company.

Table 5. Companies' Position.

Maturity stage	Total number of companies
Legal Requirements	7
Responsibility Assignment and Training	3
Systematization	8
ECO2	10
Eco-Innovation	14
Leading Green Company	13
Total	55

Table 6. Classification of the Interviewed Companies.

Company	Sector	Market	Size	Maturity stage
1	Food and drink manufacture	Globe	>250	6
2	Office products	United Kingdom and Northern Ireland	51-250	6
3	Plastic stationary products	United Kingdom	51-250	6
4	Information and communications technology (ICT)	Globe	>250	6
5	ICT	United Kingdom	0-50	5
6	Building	England	>250	6
7	Engineering, ICT	United Kingdom	>250	4

Of the 55 companies that responded to the survey, 78% of the respondents agreed with the order proposed in the maturity model. Almost 50% of the companies were positioned in one of the two most advanced stages (Table 5).

We followed up with corporate representatives who had rated their companies in one of the last three stages, and therefore could be expected to be relatively advanced with respect to their environmental management efforts. Table 6 provides information on the seven companies contacted for semistructured interviews.

These semistructured interviews enabled in-depth insights into the views of corporate representatives (Patton, 2001), and allowed to gain rich, contextual information regarding the way in which the companies within the sample progressed through the different maturity stages. Questions were open ended to elicit deeper exploration of issues and to allow the respondents' own experiences to emerge freely (Aira et al., 2003; Appleton, 1995; Ingram, 2008). Respondents perceived the model as a logical sequence of maturity stages and confirmed that their companies were moving in this direction. Respondents also revealed that each maturity stage is associated with a number of milestones, that is, key policies that at least several of the companies undertook as part of progress through the different maturity stages. This model therefore provides useful guidance for those companies that wish to further develop their environmental management efforts and strive for excellence in environmental management. Specific information from these interviews is collected in the article of Ormazabal et al. (2015).

Moreover, we carried out a multiple case study to analyze the data within each company and situation and to understand the similarities between the cases and provide the maturity model with strong and reliable findings (Gustafsson, 2017). Three case studies were carried out to demonstrate that the collected information represented the path that companies should follow toward environmental excellence. These case studies were much more exhaustive than the semistructured interviews

Table 7. Sessions and People Involved in Each Company.

Company	Number of sessions	Number of people
Railway	5	6
Elevation	9	8
Chemical	4	5

among U.K. companies, as they lasted several days and we talked to more than five people inside each company. Each interview lasted approximately 2 hours. The studied companies were from different sectors: railway sector, elevation sector, and chemical sector. Table 7 shows the number of sessions that were held, as well as the number of people from the company that were involved.

The selected companies were proactive companies as they are the ones that can provide the necessary information to validate all the maturity stages and to identify the milestones that have taken them to the highest maturity stages. Those responsible for environmental management, communications, process design, and process maintenance were interviewed in every company. In this way, we were able to study the specific evolution of the environmental management within a satisfactory number of companies. An interview guide was prepared, which listed the questions and issues that needed to be explored. These questions were grouped into the different maturity stages. The main objective was to find evidence for each of the stages identifying specific actions and the evolution over time. Some of the questions were as follows: "How has the evolution been regarding the environmental management training hours?" "In which year was the systematization implemented in a continuous improvement way?"

With all this information, we developed a system dynamics model employing Vensim System Dynamics simulation software (Eberlein & Peterson, 1992). Moreover, we used the System Dynamics Model Documentation and Assessment Tool (Martinez-Moyano, 2012) to increase transparency and facilitate communication about model elements. The instruments and model documentation are available at Ormazabal et al. (2013).

Thanks to the experience of the experts that took part in the workshops, the BOT graphs were available. As a consequence, the objective was to build a simulation model, starting from the Causal Loop Diagrams, to capture the graphs developed by the experts in the workshops. The running model contains a dynamic hypothesis of how the causal structure creates the anticipated behavior, which can then be revalidated with the expert panel.

Results

All the collected information helped in the definition of a sequence of six maturity stages companies pass through. These stages go from companies' initial efforts in environmental management toward the achievement of environmental excellence. Our informants noted a progression of maturity stages, each of which is characterized by a set of dynamic processes leading to the achievement of an indicator of success. In the maturity model literature, the names and indicators vary by the type of maturity being assessed; for example, CMMI® includes five stages, idealized and, at the higher stages, largely aspirational. Within our domain, we identify six stages of maturity, ranging from minimal requisite compliance to holistic and entrepreneurial activities that characterize strategic and competitive leadership (Table 8). Each is associated with a key indicator that captures the degree to which a firm has achieved the associated level. These states and indicators, as described in the methodology, have been defined from the GMB and have been refined and improved throughout the different research methods.

Table 8. Identified Environmental Maturity Stages.

Maturity stage	Key indicator
Stage 1: Legal Requirements	Degree of Equipment Compliance
Stage 2: Responsibility Assignment and Training	Task Compliance Degree
Stage 3: Systematization	Process Compliance Degree
Stage 4: Ecological and Economic Benefits (ECO2)	Best Available Technologies (BAT) Compliance Degree
Stage 5: Eco-Innovative products and Services	Eco-Innovative Compliance Degree
Stage 6: Leading Green Company	Communication Compliance Degree

While indicators might be treated as discrete events of achievement to be recognized in their own right, the processes that underlie them are complex, intertwined, and sometimes self-constraining. This study of how each stage is achieved starts with an idealized cascade of activities that lead to higher levels of maturity, reflecting the sequence in which they are expected to be achieved. These combine to create a partially closed model, in that the effects of resource limits and managerial decisions are not explicit.

Stock and Flow Model

All the collected information helped in the definition of a sequence of six maturity stages companies pass through. These stages go from companies' initial efforts in environmental management toward the achievement of environmental excellence. The model was calibrated to represent the evolution of the same situation previously defined: an industrial company of approximately 500 employees. The selected time horizon was 60 months. Note that this time horizon corresponds to an ideal situation. Hence, it can be different, depending on the characteristics of the company and how rapidly it implements the different improvements.

Since we are representing a prescriptive maturity model, the feedback loops characterizing higher maturity levels get triggered progressively in the environmental management evolution.

What follows is an explanation of each of the six maturity stages for environmental management. For each of the maturity stages a variable that represents the stage compliance has been defined. The variables that appear in grey in the following figures represent the connecting link with the previous stages. A company that wants to improve its environmental management has to progressively focus on each of the following states, focusing on the variables indicated in each of them. In addition, the policies that managers have to consider in each of the stages are listed. As explained in the methodology, these policies have been identified in the GMB workshops and have been refined throughout the research.

- *Legal Requirements*. The first thing that a company should do is to understand exactly the legal requirements that it should fulfill. It is fundamental to identify the laws that the company is breaking or in danger of breaking. The measures companies implement to comply with the law often start with end-of-pipe solutions that require new equipment investment to mitigate environmental impacts. Consequently, in this stage we find two main groups of stocks and flows (Figure 3). In the first stock, we find the *Acceptable Impact* [TnCO2] that is going to decrease as *New Legal Requirements* [Requirement] appear. This *Acceptable Impact* demands a lower impact what pushes the company to reduce it by *Implementing Equipment* [Equipment/Month]. As a consequence, the *Implemented Equipment* [Equipment] increases but it also decreases with the *Obsolescence [Equipment/Month]* of

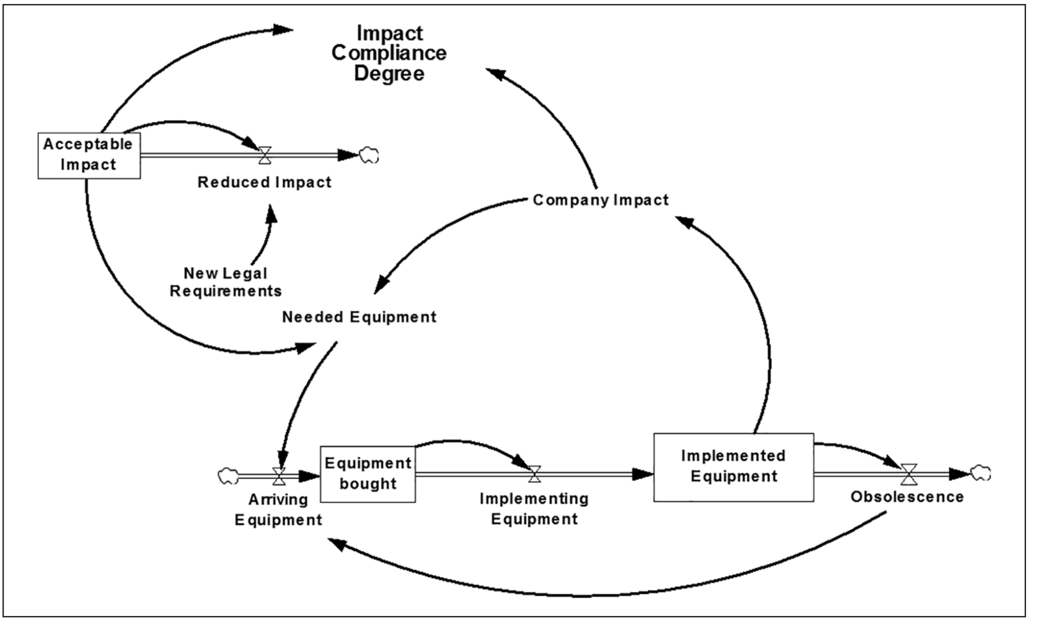

Figure 3. Stage 1. Legal requirements.

some equipment after several years using them, as it is calculated as the integral of *Implementing Equipment* minus the *Obsolescence*. The *Implemented Equipment* helps lower *the Company Impact* [TnCO2] on the environment. As a result, the *Impact Compliance Degree* [Dimensionless] has been defined to measure in which way the company is fulfilling the law and it is calculated as the *Acceptable Impact* divided by *Company Impact*.

As a consequence, managers should be aware of the following policies in this stage:

- ○ Identify and have access to the legal requirements.
- ○ Estimate the different legal environmental aspects in the company.
- ○ Invest in necessary end-of-pipe technologies.
- ○ Document and identify the level of compliance.

- *Responsibility Assignment and Training*. Once the applicable laws are identified and some end-of-pipe equipment have been introduced, some training is needed to teach the workers how the equipment should be efficiently used. This is represented with the flow *Average Training Change* [Hours/(Month × Month)] and the stock Average Training [Hours/Month] (Figure 4). The *Average Training* represents the quantity of hours on average that the company spends each month. Thanks to this training the company's environmental impact will decrease. All the training and the implemented equipment requires some control and management. Consequently, it is necessary to assign management tasks, *Needed Management Tasks* [Tasks]. As a consequence, the *New Assigned Management Tasks* [Tasks/Month] increases the *Assigned Management Tasks* [Tasks] leading to a decrease in the company's impact. The *Assigned Management Tasks* is calculated as the integral of *New Assigned Management Tasks*. As a result of this stage, the *Tasks Compliance Degree* [Dimensionless] has been defined to measure in which way the company has assigned the *Needed Management Tasks* [Tasks].

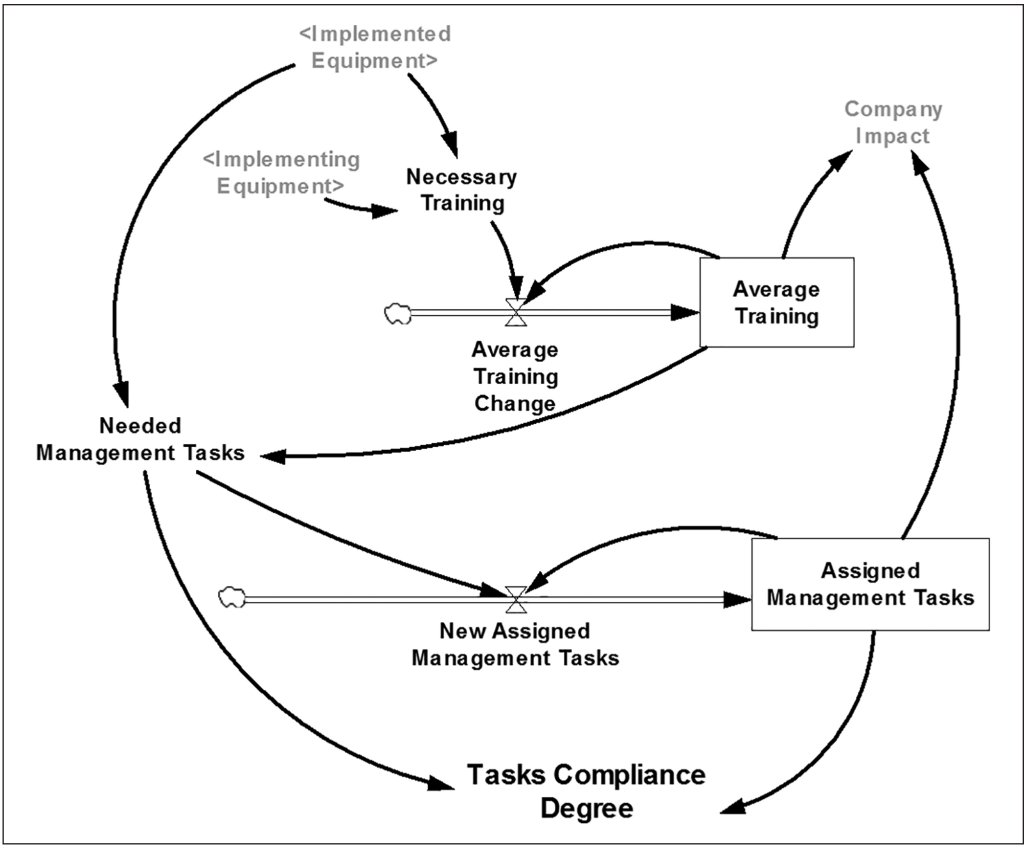

Figure 4. Stage 2. Responsibility assignment and training.

As a consequence, managers should be aware of the following policies in this stage:

- Appoint a person responsible for environmental management.
- Define and document a legal adjustment plan

1. Identify the causes of the different environmental impacts.
2. Identify the enforcement actions to be taken and in which workplaces.

- Assign responsibilities, obligations and resources for each of the actions.
- Train workers so that they have the necessary skills to carry out the environmental measures that are being planned.
- Implement the environmental actions to comply with the law.
- Review the results and see if more enforcement actions are needed.

- *Systematization*. Once they have the necessary equipment implemented, they have several indicators and procedures in place and training is given to workers, all this need to be organized and consequently systematized. The company starts *Designing Processes* [Process/Month] (flow) what leads to a higher number of *Designed Processes* [Process] (stock). Afterward they start *Implementing Processes* [Process/Month] (flow) what leads to a higher number of *Implemented Processes* [Process] (stock) improving the company's impact (Figure 5). These processes become useless after some time, hence the *Process*

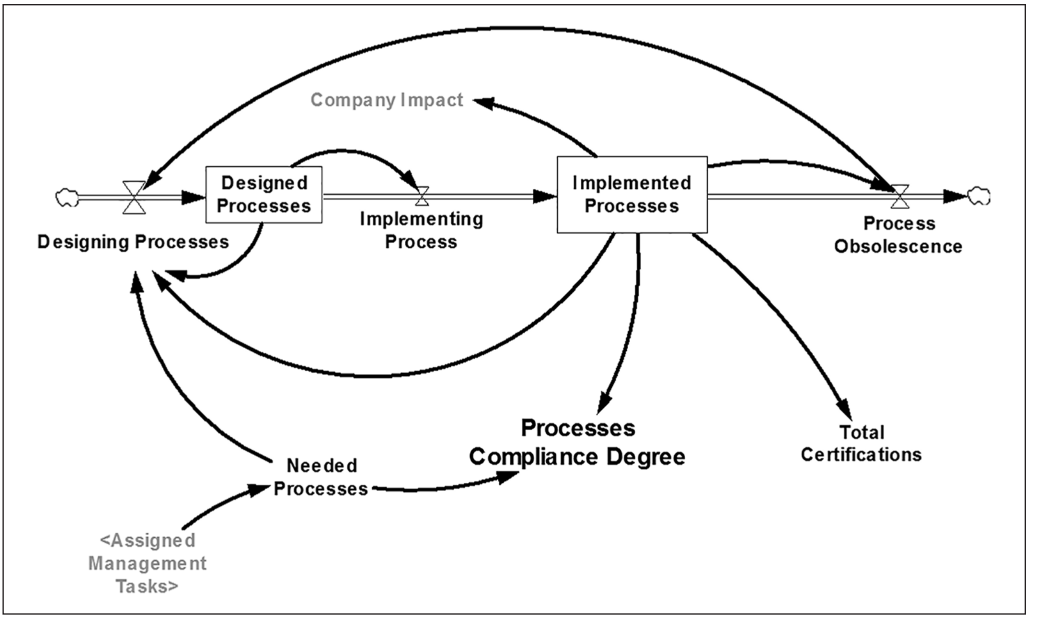

Figure 5. Stage 3. Systematization.

Obsolescence [Process/Month] (flow) decreases the *Implemented Processes*. Successful movement toward Implemented Processes allows the company to achieve an environmental management system certification such as ISO 14001. As a result of this stage, the *Processes Compliance Degree* [Dimensionless] has been defined to measure in which way the company has implemented the *Needed Processes* [Process].

As a consequence, managers should be aware of the following policies in this stage:

- Document and systematize all the environmental steps that are being carried out in the company.
- Control of records. Records must be legible, identifiable, and traceable.
- Internal audit.
- Periodic review:

1. The results of internal audits.
2. External communications (complaints).
3. Environmental performance.
4. Level of compliance with objectives and targets.
5. Status of corrective and preventive actions.
6. Follow-up of actions resulting from previous reviews.
7. Recommendations for improvement.

- *ECO2*. In the next stage, the company goes beyond the systematization. The company does not see the certification only as a "requirement" but also it sees it as the right thing to do. It is in this stage when companies realize that there are quite significant environmental benefits from a well-run environmental management system. They enter in a continuous improvement cycle. This fourth stage is called ECO2 because at this point companies

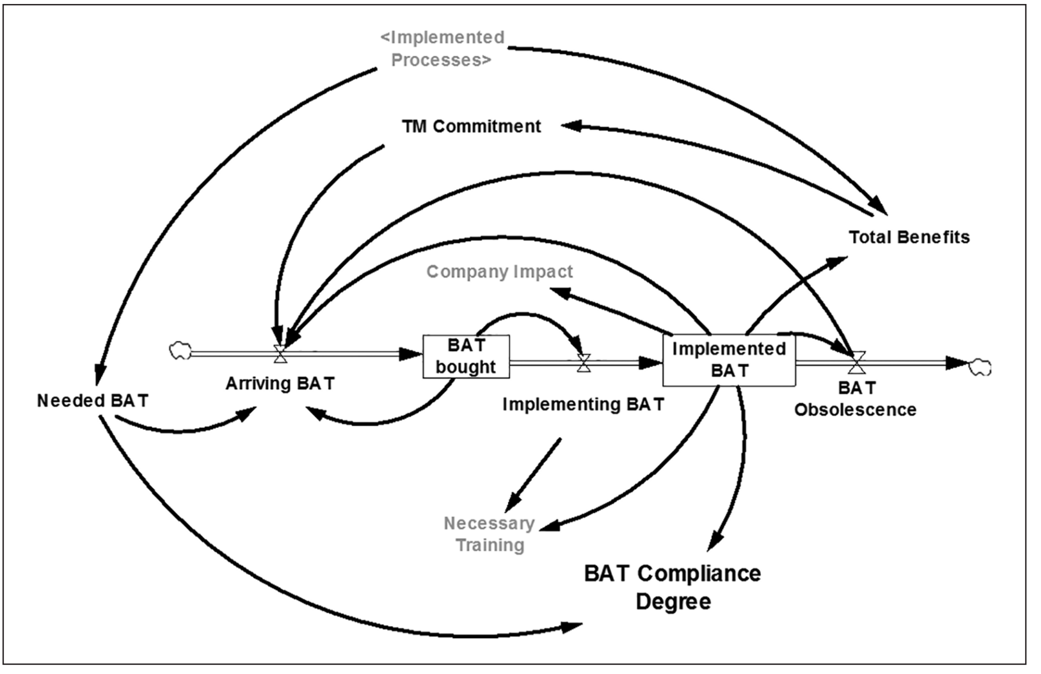

Figure 6. Stage 4. ECO2.
Note. ECO2 = Ecological and Economic Benefits; BAT = Best Available Technologies.

obtain ECO2 (Suzuki et al., 2010). They start buying BAT (Best Available Technologies) and afterward *Implementing BAT* [Equipment/Month] (flow) which increases the number of *Implemented BAT* [Equipment] (stock; Figure 6). The *BAT Obsolescence* [Equipment/Month] decreases the *Implemented BAT*. The use of efficient processes and BAT generates greater profit increasing the *Total Benefits* [Euros/Month] and the *TM (Top Management) Commitment* [Dimensionless] starts to increase. The *TM Commitment* is calculated according to the benefits that the company has obtained due to environmental management. When the top management is more committed to environmental issues, it will be more aware of the importance of buying the needed BAT. As can be seen, unlike the implemented equipment, the BAT reduces not only the environmental impact but also the use of materials, energy, water, and so on, and as a consequence the economic impact is improved. As a result of this stage, the *BAT Compliance Degree* [Dimensionless] has been defined to measure in which way the company has implemented the *Needed BAT* [Equipment].

As a consequence, managers should be aware of the following policies in this stage:

- Implement the state of systematization in the form of continuous improvement.
- Identify critical processes:

1. Generation of unnecessary waste.
2. Excessive consumption of raw materials, energy and water.
3. Inadequate use of containers and packaging.
4. Inefficient transport.

- Prioritize environmental aspects according to

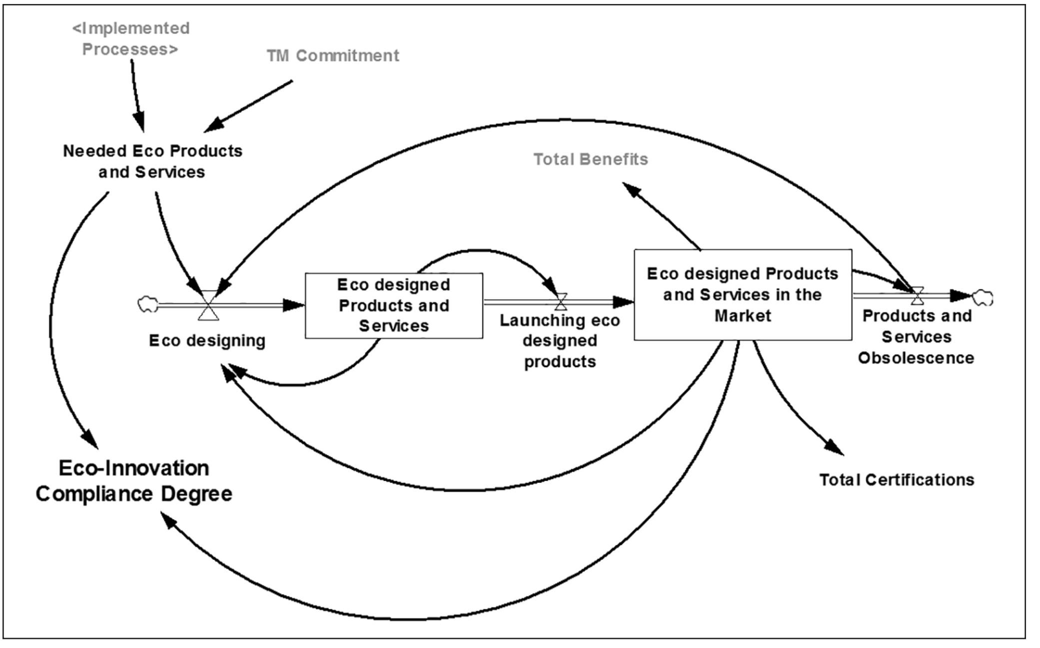

Figure 7. Stage 5. Eco-innovative products and services.

1. Quantity.
2. Dangerous.
3. Economic costs.
4. Capacity to minimize and improve results.
    - Design possible actions/solutions with economic-technical-environmental feasibility analysis.
    - Encourage the participation of workers in new ideas that can improve environmental aspects and reduce some costs.

- *Eco-Innovative Products and Services*. Once the company has achieved the systematization stage and has begun realizing operational savings, the company may recognize the value of new green products and services for the activities of the company. As a consequence, they will start *Eco designing* [Products&Services/Month] (flow) products and services that minimize the environmental impact (Wee & Quazi, 2005), increasing the number of *Eco designed Products and Services* [Products&Services] and afterward *Launching eco designed products* [Products&Services/Month] to the market increasing the number of *Eco designed Products and Services in the Market* [Products&Services] (Figure 7). The *Eco designed Products and Services in the Market* is calculated as the integral of *Launching eco designed products* minus *Products and Services Obsolescence* [Products&Services/Month]. There are different types of software and models to help companies in the acquisition and management of the product life cycle (Yang et al., 2007). In this stage, companies tend to be quite proactive so they innovate and consequently they gain more customers. Moreover, they can achieve a certification regarding the eco-design, such as the ISO 14006. As a result of this stage, the *Eco-Innovation Compliance Degree* [Dimensionless] is measured to identify in which way the company is answering to the *Needed Eco Products and Services* [Products&Services].

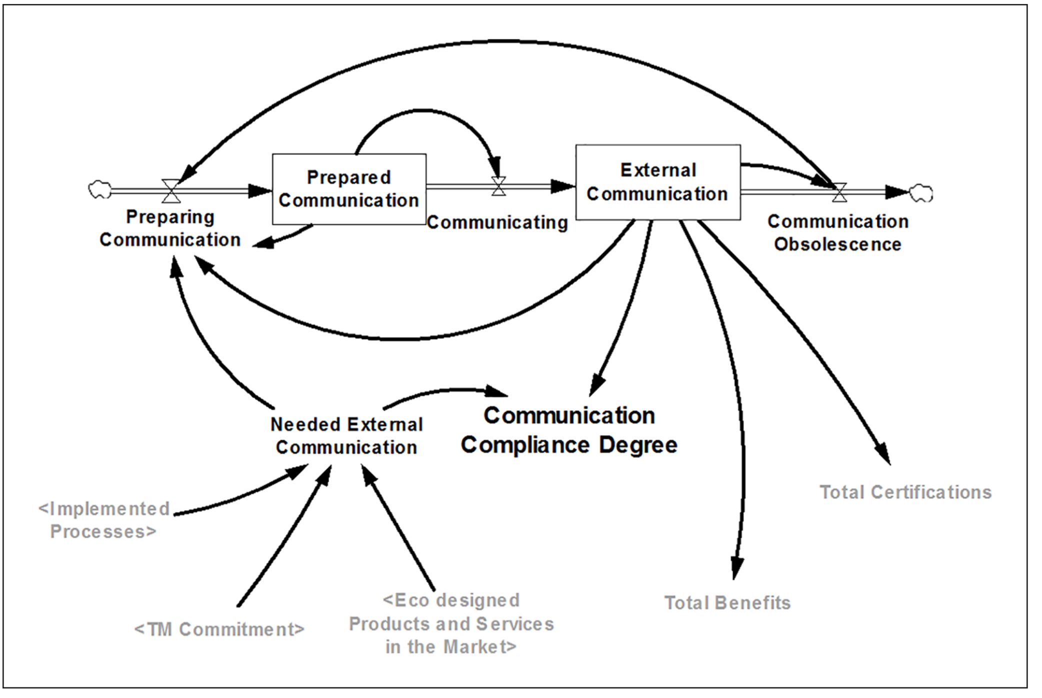

Figure 8. Stage 6. Leading green company.

As a consequence, managers should be aware of the following policies in this stage:

- Identify market demands.
- Define some objectives to know what to focus on.
- Identify the environmental aspects and impacts from the acquisition of raw materials to their final disposal.
- Cooperate with customers and suppliers.
- Evaluate each of the environmental aspects and impacts to identify the most significant ones according to the objectives.

- *Leading Green Company*. Once the stage of eco-innovation has been reached, the company focuses its efforts on becoming a green company. Companies begin to make public their environmental practices and they compete on environmental issues. Processes and green products/services are communicated externally and the top management will decide to communicate less or more depending on its commitment. In this final stage, the company should be a benchmark for other companies that want to improve their environmental management. Through *External Communication* [Hours] (stock), the whole market becomes aware of the green image of the company increasing the *Total Benefits* (Figure 8). This *External Communication* is calculated by the integral of *Communicating* [Hours/Month] minus *Communication Obsolescence* [Hours/Month]. Not only customers but also competitors look at the company as a reference company in environmental issues. As a result of this stage, the *Communication Compliance Degree* [Dimensionless] has been defined to measure in which way the company is fulfilling the *Needed External Communication* [Hours].

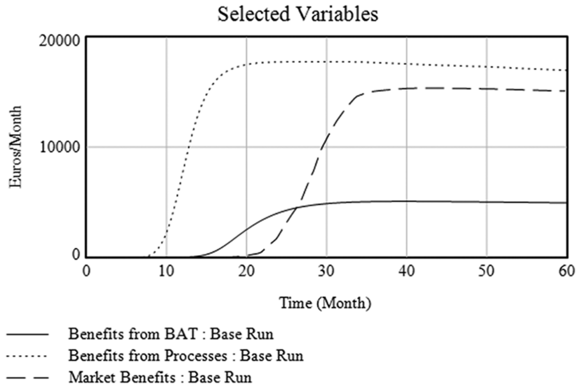

Figure 9. Benefits obtained.

It is important to highlight, that the Total Benefits will at the end be the result of the Benefits from Processes, the Benefits from BAT and the Market Benefits that come thanks to the External Communication.

As a consequence, managers should be aware of the following policies in this stage:

- Identify issues of concern to stakeholders
- Identify media and activities that have been effective in communicating with stakeholders
- Identify opinion leaders and their influence on environmental communication.
- Define the objectives of external communication/marketing in relation to

1. The environmental aspects of the different activities, products and/or services
2. The environmental actions being carried out in the company.
3. The environmental improvements,
4. The environmental objectives and goals.

- Define the geographical scope.
- Make an Environmental Statement on all environmental aspects of the company.

When we obtain the simulation, through Vensim software, of these variables, we can observe that the highest benefit is obtained thanks to the processes (Figure 9). Experts, that participated in the workshops, confirmed that this is exactly what happens at companies, as the reduction in processes' consumption (water, energy, etc.) is what causes the significantly decrease in the costs and therefore increases the benefit.

Feedback Loop Analysis

The structure, presented in Figure 10, includes some feedback loops that should be analyzed in more detail. Stages 1, 2, and 3 are dominated by balancing loops. The first stage is based in a single balancing loop (1B) that pretends to keep the company environmental impact behind some acceptable level through the implementation of impact reducing equipment. Such equipment acts as filters that avoid the emission of contaminants outside the firm. During the second stage, the environmental impact is additionally controlled though the implementation of environmental management tasks and activities to train the workforce (2B). The third stage brings the definition and implementation of

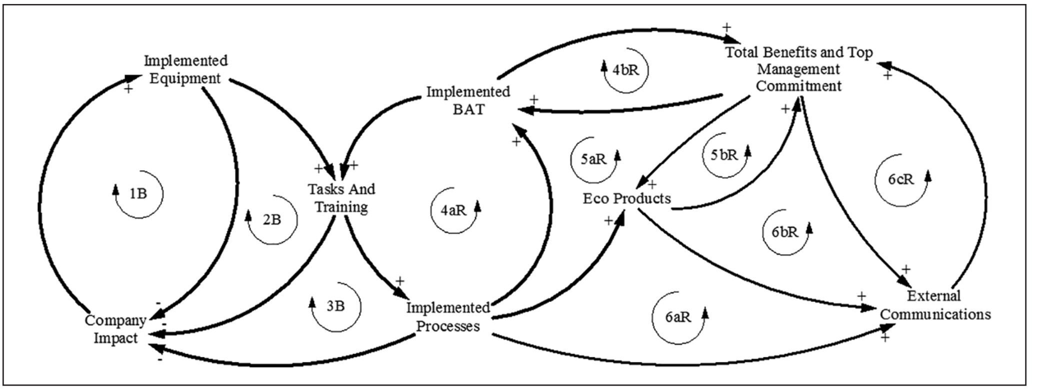

Figure 10. Stage 6. Leading green company.

procedures and processes that allow the systematization of the environmental management (3B). Again, the implicit goal of these three loops is the reduction of environmental impact.

The first reinforcing loop of the model is triggered in the fourth stage. Once the implemented processes are mature enough, BAT are implemented. These technologies differ from equipment implemented in stage one, because their goal is not only to reduce the environmental impact but also to diminish the used resources. This means that BAT have the double effect of reducing environmental impact and generating economic benefits that contribute to increase tops management commitment (reinforcing loops 4aR and 4bR).

The fifth stage adds two additional reinforcing loops to the structure, through the development of Eco-products (5bR). The development of these Eco products can also be reinforced by the implementation of new or improved processes (5aR). Finally, the sixth stage triggers three reinforcing loops, as the impulse of top management (6cR), new eco products (6bR) and improved processes (6aR) create opportunities for external communication.

Simulation Model

As noted in the introduction, the aim of this research is to demonstrate that system dynamics techniques serve to validate the conceptualizations behind a maturity model. Therefore, the next step was to build a simulation model from the causal model and to compare the simulations obtained with the graphs represented by the experts in the workshops (Figure 11 and Figure 12). The ability to render the reference behavior elicited from experts contributes to the validation of the maturity model in the sense that agreement between reference behavior and simulated behavior is a strong requirement to such effect.

For this validation phase, Vensim System Dynamics simulation software has been used to capture the problem structure (Eberlein & Peterson, 1992). The model has been calibrated to represent the evolution of an industrial company of about 500 employees. It has been simulated over a period of 5 years, which corresponds to 60 months. It should be noted that this period of time is different from that of the case studies, as it corresponds to an ideal situation and can therefore be different depending on the characteristics of the company and the speed with which the different policies described in the model are implemented.

Initial values were set based on the companies of the multiple case study. However, when calibrating the model, it was not so important the values but the evolution of the different variables, since the concrete values can change from one company to another. The model has been adjusted to achieve the behavior defined by the experts.

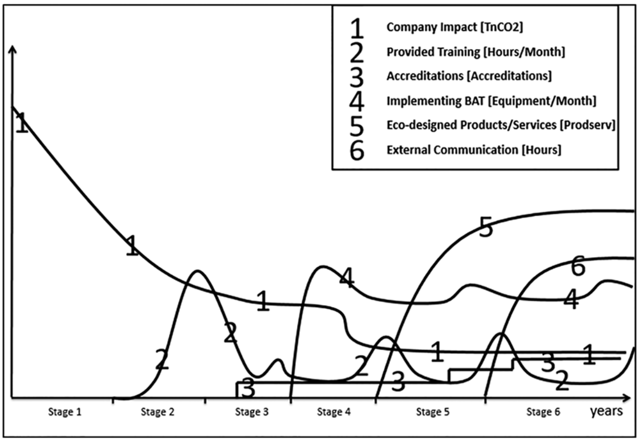

Figure 11. Behavior over time presented by the workshop experts.

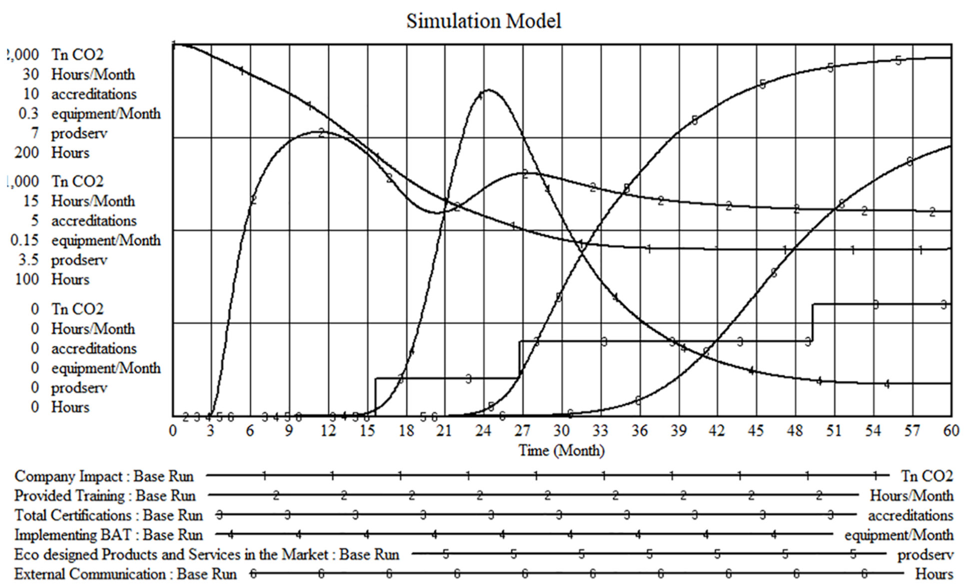

Figure 12. Simulation model behavior over time.

The simulation model represents the experts' opinion about the behavior of the environmental management in a company that was defined during the GMB workshops. New laws appear and are applied to the company. The gap between existing operations and new requirements are treated as an externally imposed change that must be met; this contrasts with the CMMI models mentioned earlier which begin their maturation process as poorly performing, but unregulated, organizations. As a consequence of these external forces, the company starts implementing new equipment to meet these requirements, leading to a decrease in the company's environmental impact (*Company Impact*). The investment in new equipment is done in support of the minimal thresholds necessary to maintain operations. Most of the effort to meet requirements occurs at entry, with incremental efforts needed to maintaining equipment over time.

We assume that the environmental impact of operations decreases from a coupling of the implementation of new equipment as well as the environmental management assignment which provides the necessary training to workers (*Provided Training*). The combination of equipment and training leads to an increase in the fulfillment of legal requirements. Training is high at this point until the desired level is achieved, and increasing again if new equipment is introduced.

When an organization progresses to the third stage, new processes are implemented. Thanks to the systematization of the processes, the company is able to obtain some certification, so the number of environmental *Accreditations* will increase.

In the ECO2 stage, the top management applies some resources to the implementation of Best Available Techniques (*Implementing BAT*) what leads to an increase, with some delay, in the *Provided Training*, as it has been pointed out before.

In the Eco-Innovative Products and Services stage the company introduces new green products and services (*Eco designed Products and Services*) what also leads to some certifications, such as, the ISO 14006, increasing the *Accreditations* variable.

Finally, it is in the sixth stage when all the environmental improvements in the processes and the innovations in the products and services are being externally communicated to the marketplace, so the *External Communication* increases.

Discussion

How does our study compare with the work by Wiesner et al. (2018)? A detailed comparison would require an article on its own. For the purpose of this article, the key question is as follows: Does Wiesner et al.'s article model for managing change toward environmental sustainability qualify as maturity model? The authors do not use this term, nor do they provide references to the literature on maturity models, neither in general nor for environmental management. Still Wiesner et al.'s model, consisting of four states: (1) Design for environmental sustainability, (2) internalization of environmental sustainability, (3) implementation of environmental sustainability, and (4) evaluation of environmental sustainability, in our opinion satisfies the definition of a maturity model of the *potential performance perspective* as opposed to our study, which targets a maturity model of the *life cycle perspective* (McBride, 2010). In the life cycle perspective, only the final stage corresponds to full maturity. The enterprise evolves over time and therefore automatically has to pass all stages to full maturity owing to improvements and learning. In the potential performance perspective, the enterprise proceeds toward increasing maturity. Wiesner's model shows the path toward higher maturity level without actually committing the enterprise to full maturity.

This study is prescriptive, adding more cases to the literature, since, as found by Wendler (2012), prescriptive approaches are less common. Furthermore, the study contributes to the literature on maturity models with a GMB approach that contributed with insight on feedback structure and provided reference behavior. Moreover, the simulation model of our study provides a proof of concept that maturity models can be validated using system dynamics—again answering a request by Wendler (2012) and a contribution to the literature.

This research proposes an environmental management maturity model that represents the evolution of environmental management within industrial companies. It extends and improves on previous research by adding, in each of the proposed maturity stages, explicit causal forces behind the evolution; understanding better how each maturity stage works. Consequently, this research goes beyond previous studies that remained at the level of generic categories (Borri & Boccaletti, 1995; Cramer, 1998; A. B. L. S. Jabbour & Jabbour, 2009; C. J. C. Jabbour, 2010; Venselaar, 1995).

This work provides evidence that system dynamics techniques can support the validation of process maturity models, an underexplored avenue in dynamic modeling. Previous authors, notably Wendler (2012), find that the maturity model literature focuses on application to particular industries and problems, with limited review of appropriateness and external validity. System dynamics can explain not only the path a system should follow toward maturity, but why particular paths are more or less effective. The presence of reinforcing and compensating feedback, while implicit in the goal of higher stages of maturity, may be addressed prescriptively or persuasively by testing the ranges and assumptions of the underlying causal model.

This model of maturity allows managers to recognize the path they have to follow to be environmentally excellent. In each of the states of maturity, they can recognize the important variables they need to improve and to move forward until reaching the environmental excellence.

Conclusions and Opportunities

Our selected problem domain is the advancement of environmental management techniques in several European countries, where there is a highly developed regulatory environment. To capture the complexity of this domain, we created a new, stage-based, maturity management model, along with the presence of triggers that intermediate between the stages at critical junctures. We engaged the techniques that are common in the system dynamics field. The modeling approach included the establishment of the problem domain and boundary through literature reviews and interviews. Group modeling workshops with subject matter experts expanded and explicated behaviors over time and possible causal structures. The behaviors were replicated successfully in a dynamic model, which was then provided to an independent cohort of reviewers through an online survey.

From the practical point of view, experts agree that companies will be able to follow the proposed model having as a reference the environmental path that they should follow. Moreover, this model helps companies understand the need for nontechnical elements in the process, such as top management commitment and workers involvement.

The SD approach helps address the concerns raised in the maturity model literature in multiple ways. First, moving from descriptions of process to well-formed causal diagrams and formal models enforces clarity of conceptualization and provides the opportunity to critique the assumptions that inevitably arise when moving from theory to empirical practice. The post-GMB survey of subject matter experts and their response to the causal model shows that the model and staged model was consistent with the expectations of a new group of informants. This is a step forward from single case-based studies.

Since maturity models, and in particular applications of the CMMI model have become extremely popular, the question arises: Is this yet a fad or do maturity models on validation lead to significant results in process improvement? We leave this question as a main challenge and motivation for future research.

The model and other artifacts generated during surveys and interaction with the subject matter experts lend themselves to extended considerations of prescriptive activity and risk-avoidance. The formal model, while still abstract, can be used to introduce the generic concepts of nonlinear response, dynamic triggers, capability traps, and limits to process maturation within organizations. In this domain, the stage-based model identified by the experts was replicated dynamically. It is important to highlight that the model presents some limitations regarding its applicability. Although many studies have been carried out to purify and validate the model, the samples used have been small. As it can be useful for all type of industrial companies, it is very general and it does not consider the specific characteristics of each company. Future research can also focus on specific sectors so the model can be more detailed depending on the sector it is operating.

Having the model opens new questions about maturity staging in environmental management: Are there opportunities or limits to leapfrog changes through technology transfer? Will changes in regulation move the slow forward, or will they distract the leader from innovating further? Is there a leverage point that can bring a process dominated by balancing structures into a form of self-funded, sustainable advancement? The conversations about these questions advance the application and usefulness of the maturity model construct beyond haphazard transfer across industries.

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ORCID iD

Marta Ormazabal https://orcid.org/0000-0002-3602-3912

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Author Biographies

Marta Ormazabal is the deputy director of Academic Affairs at Tecnun, the School of Engineering of the University of Navarra. Her research area is focused on sustainability within industrial companies and more specifically on the implementation of Circular Economy and Industrial Symbiosis. She has actively participated in research projects and has published more than 20 articles in this area.

Jose M. Sarriegi was an associate professor at Tecnun, the School of Enginnering of the University of Navarra. (He was the professor of "Information Systems", "Knowledge Management" and "Modeling and Simulation" at the Industrial Management Department at Tecnun. His research interests included Modeling Complex Systems, Crisis Management and Environmental Management.

Eliot Rich is an associate professor and chair of the Department of Information Systems and Business Analytics, School of Business, University at Albany, State University of New York. His research includes applications of modeling and simulation to problems of sustainability, information security, critical infrastructures, organizational change, innovation, knowledge management, and project management.

Elisabeth Viles is a head of the Industrial Management Department at Tecnun, the School of Enginnering of the University of Navarra and deputy director of the Institute of Data Science and Artificial Intelligence. She is also the head of the Sustainable Improvement research group. Her research area is focused on the application of statistical thinking tools and other continuous improvement methodologies in industry.

Jose J. Gonzalez was a professor for Information and Communication Technology at the Department for ICT, University of Agder, Norway, until he retired in 2019. Currently he works as Executive Research Advisor for the company Red Rock in Kristiansand, Norway.