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BUILDING A BUSINESS CASE FOR ECODESIGN IMPLEMENTATION: A SYSTEM DYNAMICS APPROACH

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Abstract

Several potential business benefits obtained from ecodesign are consistently reported by academic studies and companies. These benefits comprise increased innovation potential, development of new markets and business models, reduction in risks and costs, improvement of organizational brand, among others. However, there are still significant challenges for adopting ecodesign, specially concerning the capture and measurement of the expected business benefits. To address such gap, this paper proposes an exploratory concept of a simulation-based business case for ecodesign implementation, grounded on a System Dynamics approach. The study builds upon the Ecodesign Maturity Model (EcoM2) and the related capabilities of ecodesign managements practices, offering an integrative outlook into how ecodesign capability building can potentially affect corporate performance outcomes over time. Preliminary results point towards the potential for managers and key organizational decision-makers to use the business case simulator to assessing ecodesign benefits and testing multiple implementation scenarios (e.g. what-if questions).

Keywords: Ecodesign, Sustainability, Business case, System dynamics, Simulation

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1 INTRODUCTION

Ecodesign can be seen as a proactive approach towards the integration of environmental concerns into product development and its related processes, e.g. operations, marketing, strategy etc. (Pigosso et al., 2013). Several practitioners and academics have been reporting potential business benefits gained through the implementation of ecodesign, such as increased levels of innovation, development of new markets and business models, reduction in liability, risks and costs, improvement of organizational image and legal compliance, among others (Plouffe et al., 2011; Haned et al., 2015; ISO, 2011; IRRC Institute, 2015). However, there is a set of challenges that still hinder adoption of ecodesign in the corporate space, mainly regarding the capture and measurement of the potential business benefits (Boks, 2006; McAloone, 1998; Boks and Stevels, 2007; Rodrigues et al., 2016a). Moreover, ecodesign efforts have been primarily discussed, evaluated and assessed in terms of product-related environmental performance, based on technically-oriented measures, such as product's shape, material and energy consumption (Issa et al., 2015; Rodrigues et al., 2016b; Handfield et al., 2001). Because the ecodesign business benefits go typically beyond the single dimension of environmental performance, an approach based on the triple bottom line (Elkington, 1997; Elkington, 1994) and geared towards enabling the managerial perspective of ecodesign implementation is required (Pascual and Stevels, 2004; Pigosso and Rozenfeld, 2012) to deriving a consistent business case.

The business case for sustainability-related efforts and initiatives have been increasingly discussed in the literature for several decades (Schaltegger and Lüdeke-Freund, 2012; Carroll and Shabana, 2010). In short, a business case can be seen as a number of arguments and lines of reasoning that supports and documents the reasons why the business community should accept or advance a certain cause (Carroll and Shabana, 2010). Within the space of business cases for sustainability, the concept touches upon considering and exploring the existing relationships between voluntary environmental and social activities and corporate economic success (Schaltegger et al., 2012), alongside with questions regarding how to manage, advance and innovate on those relationships.

With a maturity-based framework for ecodesign implementation and management (EcoM2) as the main theoretical backbone (Pigosso et al., 2013), this paper draws upon the particular concept of capability of ecodesign management practices (Pigosso et al., 2013), and seeks to offer an integrative outlook into how capability building on ecodesign will potentially affect corporate performance parameters over time. These parameters may include - but are not limited to – aspects related as revenue, market share, expenses, risk, employee productivity, among others.

The focus of the research is positioned at examining the dynamics of the development of ecodesign capabilities in a corporate context. Besides the dynamic aspects, the integration of sustainability concerns into product development *per se* is also seen as a complex task, with high levels of interrelatedness among variables (Rodrigues et al., 2016; Tatikonda, 2007; Costa et al., 2014). Therefore, approach based on System Dynamics (SD) is selected. System Dynamics was initially proposed as an application of control theory to socio-technical complex systems, supported by computational modelling and simulation, and targeted at analyzing complex and dynamic behavior (Liao et al., 2015; Lee et al., 2012; Forrester, 1971; Forrester, 1995; Sterman, 2001). Some fundamental characteristics of such dynamic and complex systems are: constantly changing and past-dependent; tightly coupled and governed by feedback (solid interaction among variables with feedback loops); self-organizing (structure determines behavior over time); adaptive (resistance to change and adaptation to new policies); and non-linear (effects are not typically proportional to the cause) (Sterman, 2000; Repenning and Sterman, 2001; Sterman, 2001). Within this context, this paper seeks to offer an initial approximation through the lens of System Dynamics towards addressing the question *how does the development of ecodesign capabilities affect corporate performance over time?* This paper proposes a first exploratory and theory-driven concept of a simulation-based framework to support the business case for ecodesign implementation, targeted at key *managers* and *decision-makers* across the organization.

2 THEORETICAL BACKGROUND: THE ECODESIGN MATURITY MODEL

This paper builds upon the Ecodesign Maturity Model (EcoM2) as the main theoretical background. The EcoM2 consists of a management framework that offers a systematic, step-by-step approach for the integration of ecodesign into product development and related processes, such as procurement, manufacturing, strategy, among others (Pigosso et al., 2013). The model has been recently updated with the incorporation of new practices aimed at developing environmentally sustainable product/service-systems (PSS) (Pigosso and McAloone, 2016) and social innovation (Pigosso and McAloone, 2015). The model encompasses three main elements:

1. Ecodesign practices: comprehensive selection of over 600 practices that are classified in two main categories, according to their characteristics and object of interest (Pigosso and Rozenfeld, 2012; Pigosso et al., 2014): a) ecodesign management practices (EMP), a collection of practices related to the integration of environmental issues into the strategic and tactical levels of the product development process. The management practices are generic and applicable to any company, regardless of product characteristics (Pigosso et al., 2013), and b) ecodesign operational practices, product-related practices directly connected with technical characteristics of product design and elements of its material life cycle.
2. Maturity levels: set of successive stages for the integration of sustainability aspects into product development processes;
3. Application method: a prescriptive approach based on continuous improvement to support companies during the implementation of ecodesign-related projects and management phases.

The maturity levels are based on the assessment of the ecodesign management practices (EMP) defined as a combination of the **(i)** evolution levels and **(ii)** capability levels (Pigosso, 2012; Pigosso et al., 2013). The 5 evolution levels defined by the EcoM2 represent a recommendation of the stages to be trailed towards ecodesign implementation. The evolution is built from *evolution level 1*, in which the company displays little experience in ecodesign and the company does not typically apply ecodesign practices, up to *evolution level 5*, when the company fully incorporate environmental concerns into its corporate, business and product strategies (Pigosso et al., 2013).

Regarding the capability levels, the model also defines a 5-point capability scale for qualitatively measuring how well the company applies an ecodesign management practices, based on the CMMI (Chrissis et al., 2011; Pigosso et al., 2013). Capability level 1 (*incomplete*) means that a practice is not considered at all or is applied in an incomplete form. Capability level 2 (*ad hoc*) says that a practice is only applied to accomplish specific tasks or correct targeted problems, i.e. in an ad hoc way, while capability level 3 (*formalized*) means that the practice is formalized in structured documents and processes, with the right resources, infrastructure and responsibilities in place. One step further, capability level 4 (*controlled*) brings the ecodesign management practice to a controlled/monitored space, meaning that performance is measured and monitored with the support of key performance indicators. Finally, capability level 5 (*improved*) means that the ecodesign management practice has its performance continuously and systematically improved over time, based on measurement and monitoring (Pigosso et al., 2013).

Built around the systematization and organization of ecodesign practices according to maturity levels, the EcoM2 offers an application method with 4 overall steps, organized in two main phases. **Figure 1** displays the schematic representation of the EcoM2 application method, with the main outputs and the positioning of the business case. Phase 1 consists of 3 main steps: 1) the diagnosis of the current maturity profile, whose main output is the current capability levels of the management practices; 2) the definition of a vision for improved maturity, according to the company's strategy and drivers, and whose main output is the desired capability levels for the management practices and 3) the deployment of actionable roadmaps of improvement projects, based on the gap between current capability levels (*Step 1*) and desired capability levels (*Step 2*). The second phase encompasses the implementation of the improvement projects that are outlined in the roadmaps, along with strategies for change management and progress measurement (represented in Figure 1 as *Step 4*).

The business case plays a crucial role specifically in bridging the gap between the deployment of structured roadmaps and their real and consistent implementation. The business case simulation framework uses the current and desired capabilities derived from Steps 1 and 2, respectively, to simulate the expected behavior of selected corporate performance indicators over time. This is considered under a specific set of circumstances and assumptions that are outlined in this paper on Section 4.

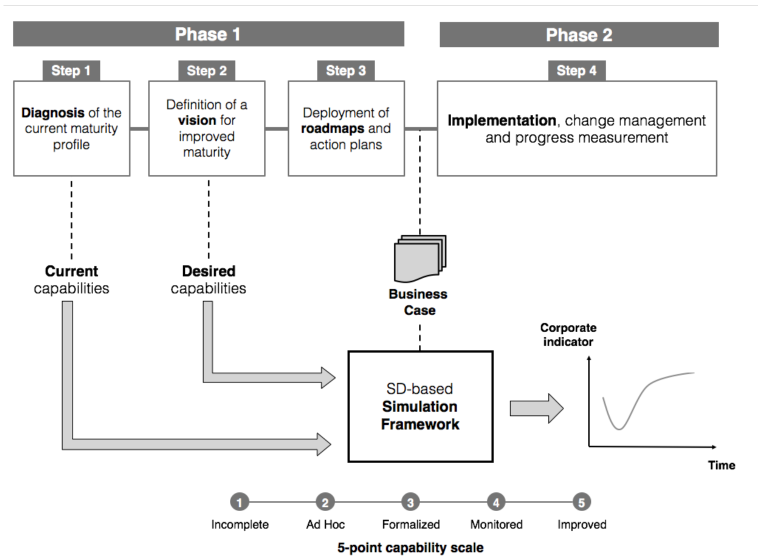

Figure 1. Schematic representation of the EcoM2 application method, the main outputs and the positioning of the business case simulation framework

3 RESEARCH METHODOLOGY

The theory-driven research methodology adopted in this paper was built around a generic System Dynamics approach based on (i) conceptualizing the system and the problem; (ii) formulating variables, relationships and parameters; (iii) testing and evaluating model's behavior and (iv) analyzing policies and use (Luna-Reyes and Andersen, 2003; Lee et al., 2012; Sterman, 2000). Within this frame of research and aimed at building a first exploratory concept of the business case simulation framework to analyzing the dynamic behavior of ecodesign implementation, the research methodology was designed with 4 steps, involving the development of the theoretical foundation for the business case simulation framework. The steps are described as follows:

1. **Literature analysis:** the relevant literature was analyzed mainly in regards to the **(i)** EcoM2 management practices, **(ii)** the reported business benefits of ecodesign implementation and management and **(iii)** evidences for building the initial assumptions for the quantitative relationships in the System Dynamics model (Luna-Reyes and Andersen, 2003). Due to the exploratory nature of this research, a sub-set of the ecodesign management practices was selected. The underlying reasoning for this selection was to follow established practices in the field of quantitative modelling – specially for SD models – which assert that a preliminary working model should be valued over greater level of details, which can be added only as necessary (Sterman, 2000). With that purpose in mind, the ecodesign management practices covering the areas of **(i)** end-of-life and related strategies; **(ii)** product's concept, requirement and trade-off management and **(iii)** evaluation and communication of product's environmental performance were selected.
2. **Cross-content analysis:** the selected ecodesign practices were then cross-analyzed: **(i)** against selected business benefits, reported in specialized literature as gained through the implementation of ecodesign and broader sustainability-related initiatives under the business case framework proposed by (Willard, 2005), and **(ii)** against each other with a view to deriving the existing interrelationships among the practices in terms of their influence on each other.
3. **Qualitative modelling based on causal loop diagram (CLD):** the causal loop diagram is a conceptualization tool that captures the relationship among relevant variables and represent the feedback processes, which in turn drive the dynamics of a system (Sterman, 2000; Lee et al., 2015). The sub-set of ecodesign management practices defined Step 1 formed the basis of the CLD. Furthermore, the practices' relationships with the corporate performance outcomes - materialized as a result of the literature analysis (Step 1) and cross-content analysis (Step 2) – were also explored and outlined in the CLD. The methodological approach for building the CLD follow the guidelines defined by Sterman (2000) and recommendations and procedures outlined by the overall methodology of Group Model Building (Vennix, 1996). With iterative processes, the main variables and influencing factors were elicited based on the specialists' knowledge, judgment and

experience;

4. **Quantitative modelling based on stock and flow diagrams (SFD)**: the qualitative CLD was then transformed into a stock and flow diagram, which aims at describing the accumulations (stocks) and rates of increase/decrease (flow), based on the variables on the CLD (Liao et al., 2015; Dangelico et al., 2010; Sterman, 2000). At this stage, it is also common to add new variables that are relevant for a better representation of the simulation and the system's structure (Liao et al., 2015; Geum et al., 2014). For the exploratory purposes of this paper and due to limitations of time and space, a working simulation model was built and tested for 2 practices within the selected sub-set of EMP. The practices were selected due to their particularly different scopes, and profiles of influence on the performance outcomes. Furthermore, only two practices were selected so an in-depth exploration of the fundamental modelling structures, details and challenges could be carried out before developing a larger, more detailed and complex business case model. Both the CLD and the SFD were built using the software package *Stella Architect* version 1.1.2, developed by *isee systems*.

4 RESULTS AND DISCUSSION

4.1 Structure of the model: the causal loop diagram

In the causal loop diagram, the relevant variables are connected by unidirectional arrows, which represent causation (causal arrows), as opposed to simple correlation between variables. Each one of these causal arrows have a polarity assigned, being either positive or negative. If a generic variable A is the cause of generic variable B (A → B), the positive polarity (+) means that *"if A increases, B will always be higher than it would have been"*, while a negative relationship (-) amounts to the fact that *"if A increases, B will always be lower than it would have been"* (Sterman, 2000, p.141). A simpler, yet non-rigorous way of perceiving the polarities is to interpret the positive polarity as *"A and B move in the same direction"* and negative polarity as *"A and B move in the opposite direction"* (Sterman, 2000, p.141). Formally, the positive link A → B is defined as $\partial A/_{\partial B} > 0$, whereas the negative link A → B is defined as $\partial A/_{\partial B} < 0$.

The final CLD obtained through the performance of the described method is illustrated in **Figure 2**. The polarities and main feedback loops are highlighted in the diagram. The positive feedback loops are self-reinforcing and, therefore, denoted with the letter **R**. Reversely, the negative loops are balancing (self-correcting) and, therefore, takes a letter **B**. All negative feedback loops have goals, which represents the desired state of the system (Sterman, 2000). In this particular CLD, all the goals are explicitly described as the practice's desired capability level (marked in **green** in the CLD).

According to the criteria defined in the methodology section, the following six EMP were selected (Pigosso et al., 2013): **1)** monitor the product environmental performance during use and end-of-life (EMP 1); **2)** communicate the environmental performance improvements as part of the total value proposition of the product, exploring the green marketing opportunities (EMP 2); **3)** evaluate the environmental performance of products during development (EMP 3); **4)** consider the environmental performance as one selection criteria for the product concept and design options (EMP 4); **5)** manage trade-offs among the environmental requirements and the traditional requirements of a product (e.g. cost and quality) (EMP 5) and **6)** find new ways to deliver the functions with a better environmental performance (EMP 6). All the practices are marked in **blue** in the CLD.

Since the practices can be seen as activities carried out throughout the product development process, key outputs of such activities were explicitly depicted in the CLD as a connecting layer to the higher-level performance outcomes (benefits). The practice's outputs are marked in **black** in the CLD, whereas the performance outcomes are marked in **bold blue**. Furthermore, each one of the selected practices has their respective mechanisms of capability building and capability erosion, inspired by the concepts in the literature of capability dynamics (Rahmandad and Repenning, 2016) and performance heterogeneity (Dierickx et al., 1989). The variables of capability building and capability erosion are marked in **brown** in the diagram. All the reinforcing (R) and balancing (B) loops in this diagram have the same structure. The reinforcing loop represented by the variables "capability level → capability erosion → capability level" is based on the idea that as capability *increases*, erosion *decreases*, if everything else is held equal. Similarly, the *higher* the erosion, the *lower* the capability will be, *ceteris paribus*. The two negative links form a self-reinforcing loop.

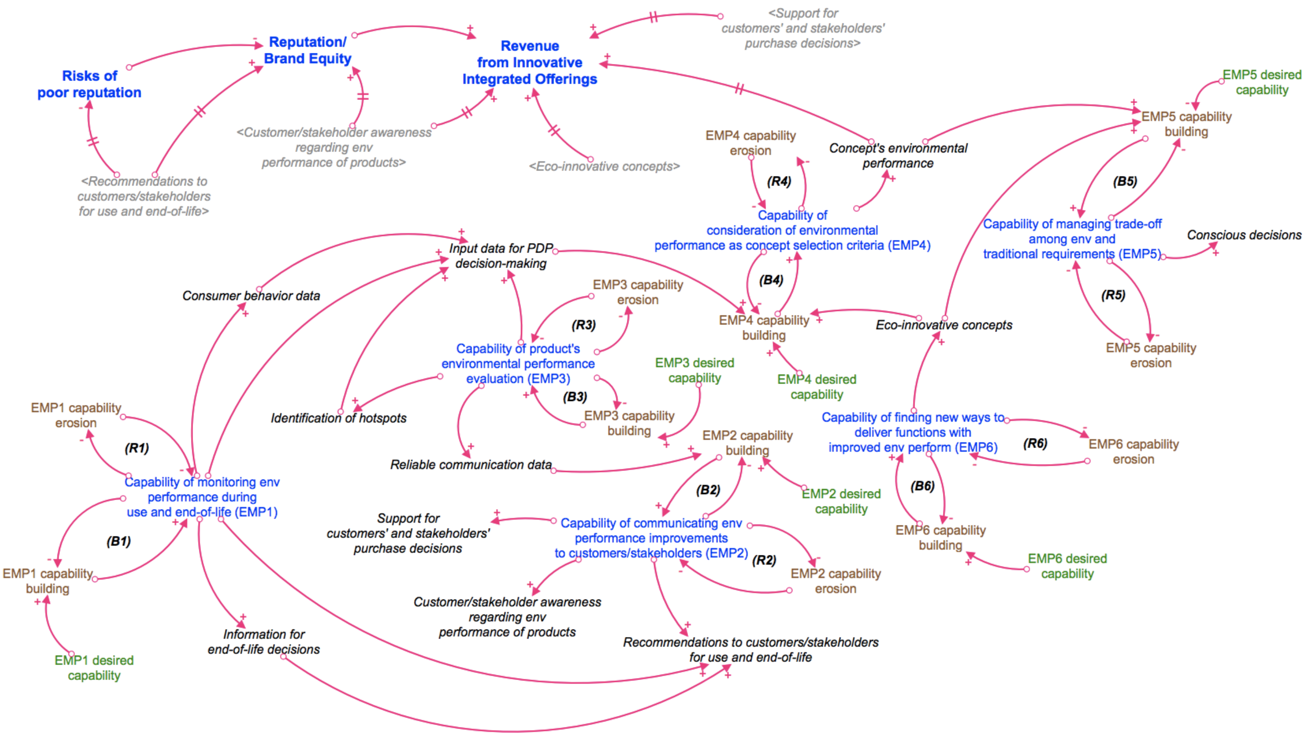

Figure 2. The resulting causal loop diagram for the business case modeling and simulation

Additionally, the balancing loop represented by the variables "capability level → capability building → capability level" represents the notion that the higher the capability, the lower the levels of capability building that will be required to reach the goal (desired capability), whereas the higher the capability building effort, the higher the capability level, if everything else is held equal. The negative and positive links form the balancing loop, with the desired capability level as the explicit goal. For simplicity and to avoid excessive repetitive variables in the CLD, we have not added the current capability levels in the diagram, since it will be represented as a property of the capability level in itself (initial value or starting point).

All the outputs – results from the practice's application – are displayed in the diagram with a positive link from the practice's capability level. This type of relationship means that the higher the capability level of a practice, the higher the *consistency* and *relevance* of the related output. As an example, if the capability of EMP 1 ("monitor the product environmental performance during use and end-of-life") is increased, then **(i)** consumer behavior data; **(ii)** information for end-of-life decisions and **(iii)** recommendations to customers/stakeholders for use and end-of-life will be more consistent and relevant, which – in turn – can generate superior corporate performance. It's also noteworthy that the CLD considers and structures **(a)** the relationship among different outputs and **(b)** the relationships between the outputs and the practice's capability level – for instance, the output from EMP 3 "input data for PDP decision-making" supports the capability building for EMP 4. This type of relationship is due to the fact that the practices are relatively independent of each other in terms of capability development, however one practice's output might facilitate the capability development for another practice.

Some of the outputs were selected and then, in turn, connected to three key performance outcomes (benefits), retrieved from the literature: **1)** risks of poor reputation (Willard, 2005; Saeidi et al., 2015), **2)** reputation and brand equity (Saeidi et al., 2015; Park et al., 2014; Maden et al., 2012) and **3)** revenue from innovative integrated offerings (e.g. combinations of products and services) (IRRC Institute 2015; Willard 2005; Clemens 2006; Schaltegger et al. 2012). The outputs that are directly linked to the performance outcomes are replicated in the diagram with a **light grey** color, meaning they represent "ghost variables" (replications of existing variables). This occurs as a way to improve the readability of the model and avoid crossed arrows in the diagram. Note that the majority of the connecting arrows in the performance outcomes are marked with double parallel bars, which signifies the importance of delays in those relationships. Delays are crucial in describing and understanding dynamic systems (Sterman, 2000).

4.2 Behavior of the model: the stock and flow diagram

The SFD quantitatively depicts the dynamics and the emergent behavior of the system's representation. Conceptually, stocks are variables which accumulate over time, while flow are rates which alter the system's state (Sterman, 2000; Lee et al., 2012). The fundamental stock-flow structure of this model relates to the representation of the capability levels as stocks, and the variables of capability building and capability erosion as flows. This formulation was inspired by well-known applications of System Dynamics in the analysis of corporate capability dynamics (Repenning and Sterman, 2001; Rahmandad and Repenning, 2016). All the three performance outcomes (risks of poor reputation, reputation/brand equity and revenue from innovative offerings) are also represented as stocks, with specific flows for representing their increase and their erosion. The simplified version of the SFD – containing **EMP 2** *("communicate the environmental performance improvements as part of the total value proposition of the product, exploring the green marketing opportunities")* and **EMP 6** *("find new ways to deliver the functions with a better environmental performance")* – is represented in **Figure 3**.

The capability stocks are initialized with the current capability. The capability building flow is constructed based on the fundamental System Dynamics structure know as *"stock management structure"* (Sterman, 2000, p. 524) – the formulation takes into account the adjustment for stock and the expected outflow (capability erosion). This formulation is used since the capability structure is goal-seeking, aiming at achieving the desired capability level set for the practice. Additionally, the capability erosion flow is based on a graphic function (or table function), in which the erosion increases when the capability increases from 1 to 2 – the point at which it reaches the peak - and then decreases once the capability grows from 2 onwards. The erosion mechanisms are basically grounded in the idea of "organizational forgetting", which has turnover and insufficient organizational memory systems as the main causes (Rahmandad and Repenning, 2016).

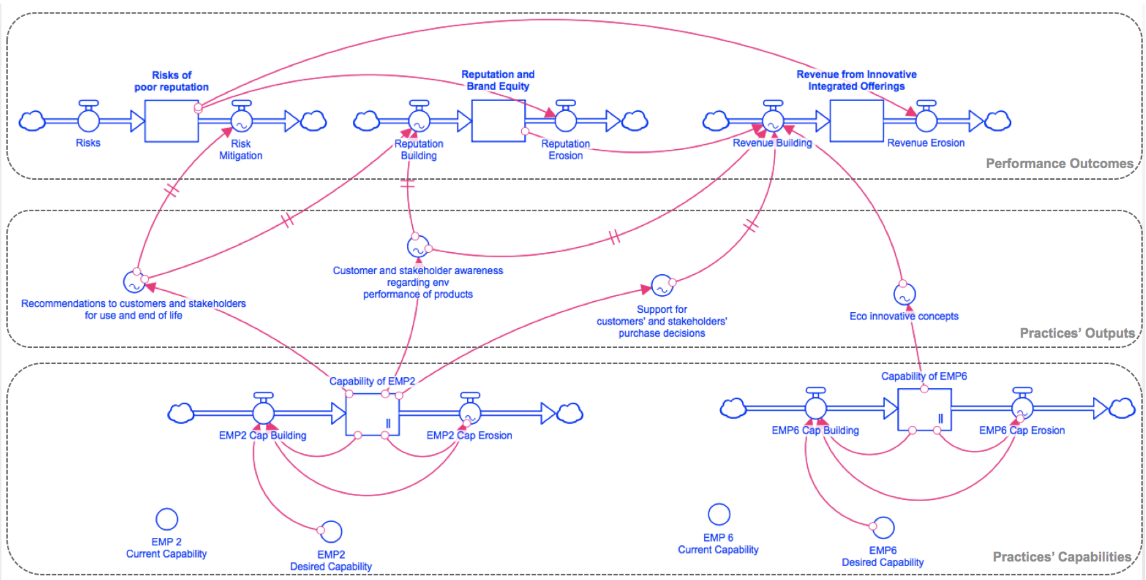

Figure 3. The 3-layered simplified stock and flow diagram for the business case simulator

On one hand, EMP 2 has three main outputs: **(i)** recommendations to customers and stakeholders for use and end-of-life; **(ii)** customer and stakeholder awareness regarding the environmental performance of products and **(iii)** support for customers' and stakeholders' purchase decisions (e.g. empowering them with information for making better decisions). On the other hand, EMP 6 displays only one output: eco-innovative concepts. The patterns of behavior for these four outputs were based on assumptions informed by clues in the literature, expert judgment (Lee et al., 2012; Lee et al., 2015) and previous applications of the EcoM2 model in organizational contexts in manufacturing companies. All assumptions were constructed with table functions in the software package. The simulation was set to run for *48 months* (four years), since a characteristic ecodesign implementation roadmap might take up to 24 months to complete, and the organization might typically reap the performance benefits within 4-year range. The delays are explicitly considered in all the relationships with delay marks.

Furthermore, random effects are considered in the risks' flow, the reputation erosion flow and in the revenue erosion flow. This is due to the exogenous nature of those variables, which are not being considered within the boundaries of this model. Since we cannot accurately predict or estimate the external/market influences on risks, revenue and reputation, we have set random distributions to play a role in eroding reputation and revenue, and building systemic risks for the organization. Recognizably, this can be further explored and improved in later versions of the simulation model. The parameters were constructed based on literature points of reference (IRRC Institute, 2015) and relative arbitrary scale (dimensionless - %), which is intended to be used as a source for investigating potential increase/decrease of performance outcomes, based on a current base case. Therefore, these indexes are intended to represent the *potential relative contribution of ecodesign to the performance outcomes*.

A sensitivity analysis was performed for the simulation model, with 6 different scenarios, based respectively on the current capability of practice 2, desired capability for practice 2, current capability of practice 6 and desired capability for practice 6. **Figure 4** shows the curves of each one of six scenarios for the three performance outcomes, with the respective labels showing the parameters in the abovementioned order. For instance, the solid blue line shows the scenario in which the current capability for both practices 1 and 6 is set as 1, whereas desired capability for both practices is 5.

Under the considered generic assumptions and circumstances, the risks of poor reputation seem to be more sensitive to the initial conditions of the capability (current capability), with higher and more persistent risks for scenarios starting with capability 1 for both practices. When current capabilities are high (greater or equal 3), the risks fluctuate around very low values. Furthermore, the reputation and brand equity shows a behavior similar to revenue, however it tends to be more sensitive to the increase of capability, compared to revenue. Performance increases in reputation and brand equity are materialized faster in this example due to the nature of EMP 2, which is based on stakeholder's awareness and the development of recommendations for use and end-of-life. These aspects - if systematized through the increase of capability - can benefit the company faster than the materialization of revenues, which depends upon the development and commercialization of new or improved versions of products and/or services. Therefore, the delays involved for reaping revenue benefits are particularly longer than the ones for reputation. However, this fact is counterbalanced by the exclusive influence that EMP 6 has on revenue, which makes it closer to the overall behavior of reputation and brand equity. Clear exceptions are manifested when the current capability of practice 2 is particularly low, cases in which the reputation erosion dominates the behavior and presents very discreet improvements in reputation/brand equity (green and purple dashed lines).

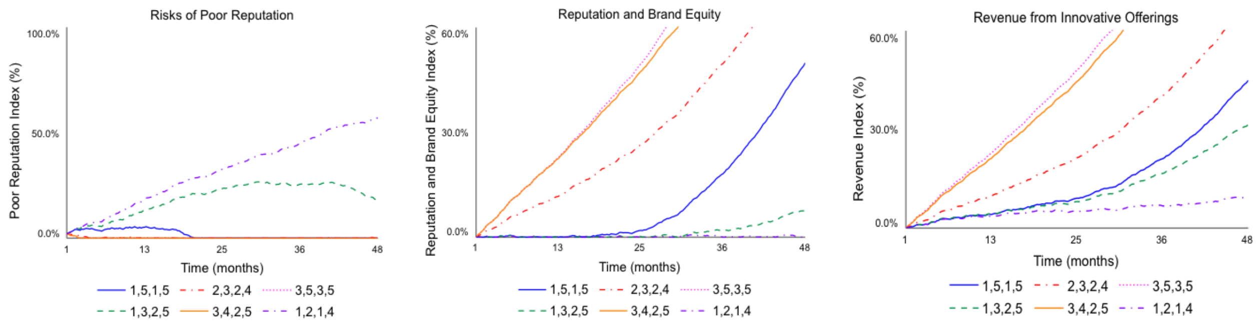

Figure 4. Summary of sensitivity analysis based on six different scenarios for current and desired capabilities of practices 2 and 6

It is also important to emphasize that, in this illustrative example, EMP 2 dominates the influence on the performance outcomes, since its outputs have direct influence on all three of them, whereas EMP 6 outputs are exclusively linked to the revenue outcome. This explains the modest increment in revenue when EMP 2 is being increased from 1 to 2, while EMP 6 is building capability from 1 to 4.

When the desired capability for practice 2 is low (capability 2) or medium (capability 3), and the current capability of both practices is low (capability 1), the risk erosion dominates the behavior, with the same happening for reputation and brand equity. This does not mean that the company is absolutely exposed to an unacceptable degree of risks, but rather that the efforts on ecodesign capability development are not being sufficient to counterbalance the negative effects of systemic risks and benefits' erosion. Finally, if we look into the "longest capability development journey" scenario, with capabilities moving from 1 to 5 for both practices, we see a *"worse-before-better"* type of behavior for the risks. This means that sometimes, under the development of ecodesign capabilities, companies might face higher degrees of uncertainty and materialized risk, which will later be offset by the emergence of improved performance outcomes, such as revenue and reputation.

5 CONCLUDING REMARKS

This paper presented a first exploratory concept of a business case simulator for ecodesign. It is expected that decision makers use the tool to assess the potential benefits of ecodesign and test multiple scenarios (*what-if questions*) with a view to deriving more robust implementation policies, in alignment with corporate sustainability strategy and main drivers. Indeed, the modelling and simulation approach is an ongoing and iterative activity aimed at refining the dynamic hypothesis and generating insights on the system's behavior. Since the model presented in its current form is a first approximation of what the dynamic hypothesis would look like and how the basic modelling structures could be arranged and defined, limitations of the study can be pointed out: (i) the initial assumptions and the preliminary state of the model limit the full utility of the results; (ii) some variables, such as the capability erosion, are highly aggregated and can therefore be broken down into other relevant variables (e.g. turnover and "organization memory" factors).

The paper's main contribution resides in laying out a first rationale upon which a full and operational ecodesign business case can be built. Therefore, the potential areas of future research include: (i) extending the model to other areas of ecodesign practices; (ii) systematizing data collection and validation through the use of qualitative methods in order to overcome the absence of historical data (e.g. interviews and case studies in corporate contexts); (iii) developing more robust indexes, parameters and patterns of behaviors for the variables relying on the use table functions and (iv) instantiating advanced future versions of the model with case company data.

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