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A Framework for the Application of Eco-efficiency to the Technology Development Process

Mauro Caetano¹, Juliano Bezerra de Araújo², Daniel Capaldo Amaral³

Abstract

The use of technology development process (TDP) models by the enterprises can contribute to the usage control of natural resources of technologies before or after its integration on products, services or processes. Although the choice of a technology can consider the use of some performance metrics to identify their eco-efficiency, the literature about technology development models neglects this element. Based on a qualitative analysis of existing models, this paper proposes a conceptual model for the adoption of eco-efficiency indicators in the TDP by the innovation managers, distributed in three different stages: the initial stage, during the planning of a technology, the intermediate stage, at the technology development, and the final stage, at the technology transfer. Future research, such as prioritizing the indicators and the extent of the present analysis to other sustainability dimensions are suggested for structuring a sustainable model of TDP.

Keywords: Innovation management; eco-efficiency; environmental sustainability; technology development; technology planning; technology transfer; theoretical model.

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Introduction

The technology development through the generation and transmission of new knowledge, development of technical skills, machinery and equipment, constitutes a fundamental factor to the promotion of innovation in the enterprises. This makes possible the insertion of these technologies at the market through a product or service which can generate business value. However, besides the need to promote innovation, the growing concerns around the use of natural resources brings the additional challenge of incorporating in the innovation process the factors related to the environmental sustainability.

It is possible to note that the discussion about environmental sustainability commonly falls in the realm of product development. Many studies are concerned with developing techniques to evaluate existing technologies and the selection of those that produce the least natural impact (Advance, 2006; Figge and Hahn, 2005; Jappur et al., 2008; González-Jiménez et al., 2001). One of the challenges of innovation management at enterprises is to foresee the environmental impacts that may be caused from technologies and how to select those which are more eco-efficient as possible. This must be analyzed relating performance and consumption of natural resources, such as energy, water, and emission of greenhouse gases, among others.

Although studies such as those of Carrillo-Hermosilla, Río and Könnölä (2010), Ende et al. (1998) and Rodrigues, Buschinelli and Avila (2010) present some of the particularities of eco-innovation and technology assessment, the authors

do not demonstrate the activities which was carried out in companies to promote innovation considering the ecological aspect.

One of best practices on this theme could be to anticipate that discussion evaluating and preparing the technology still in its early stage of development, during the process of technology development. There are several TDP models in the literature of innovation management (Clark and Wheelwright, 1993; Clausen, 1993; Cooper, 2006; Creveling et al., 2003; Sheasley, 2000). However, from a systematic review of these models, gaps were identified regarding the theme of sustainability, particularly the use of natural resources. Currently, this constitutes an essential element for companies that consider at their strategy not only economic efficiency of business, but also the environmental preservation and rational use of natural resources (Ayres, 1996).

The use of performance indicators can be an alternative for decision making in companies. In this sense, this study seeks to analyze aspects related to the use of eco-efficiency indicators in the TDP to verify the possibility of using these indicators in a proposed theoretical model, contributing to the sustainable management of innovation. The next sections present the background with the aspects of eco-efficiency indicators and the technology development process models.

Eco-efficiency indicators

Eco-efficiency, according to Ayres and Miller (1980), is understood as the management capacity of an organization to convert natural resources into a set of goods or services to

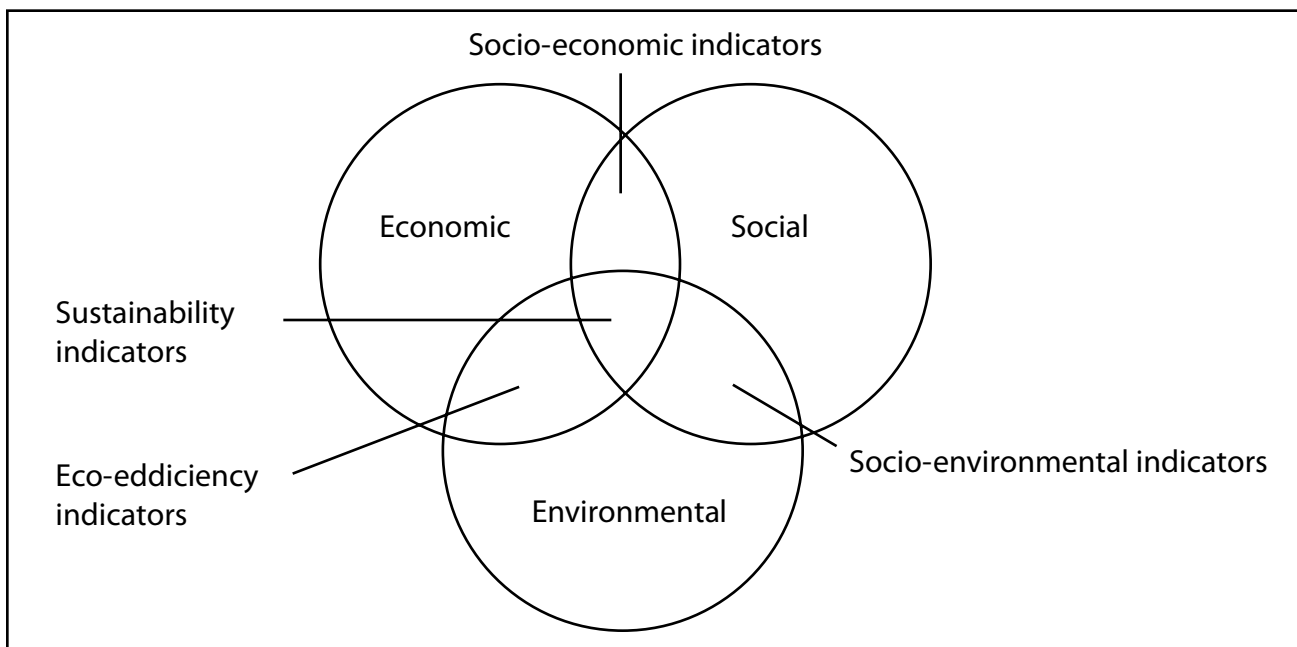


Figure 1: The different dimensions of sustainability indicators and the scope of the study. Sikdar (2003).

the consumers. This statement can be considered two distinct scenarios, one in which it produces the same amount of products with fewer resources, or else one in which it is possible to produce more products with the same amount of resources. The better performance of the particular means of production, which in this case refers to tangible technologies, such as machinery and equipment, for their inputs and outputs, here referring to natural resources, eco-efficient technology that presents itself.

To Jappur et al. (2008), the use of eco-efficiency in production strategy involves the combination of economic performance with environmental performance of the means of production in order to promote corporate sustainability, thus becoming a critical factor for business success. Although the term “sustainability” is associated with the triple bottom line model in their three dimensions, social, economic and environmental (Elkington, 2004), it is often used in literature to deal with only one or other of these dimensions, such as this study, which focuses on eco-efficiency of a given technology, covering environmental and economic dimensions. That does not mean that an eco-efficient technology is characterized as a sustainable technology, but rather a form of contribution to corporate sustainability, particularly in the better use of natural resources in relation to their performance. The scope of this study is shown in Figure 1 relating the eco-efficiency to the sustainability (Sikdar, 2003).

There are several studies which propose to measure the company eco-efficiency based on the use of indicators, as presented by Figge and Hahn (2005), which suggest the identification of the opportunity cost from the use of natural resources. The company that produces the best financial return in relation to natural resources, evaluating all of its processes are those that, according to the authors, creating the best sustainable value to the market.

Also Advance (2006), from a study of 65 companies from 16 different European Union countries, presents the “sustainable value” created by the company, analyzing its revenues in light of all the inputs and outputs of natural resources in their process industrial. These values are compared with a benchmark of income and consumption of a group of 15 countries belonging to the economic bloc, called E15 benchmark. From this comparison it was identified firms that contribute most to the sustainability of the block and that more needs to step up its own industrial processes in order to improve their eco-efficiency.

With the existence of different choices of tools and methods for assessment of environmental sustainability, companies have opted for the use of performance indicators, seeking to better themselves based on the idea that “what is measured can be managed” and performance indicators have helped companies identify and abandon intensive technologies in resource consumption (Azapagic, 2004).

This study presents a set of 14 systems of performance measurement in environmental sustainability, which could be used in TDP models in order to increase their eco-efficiency, namely: Azapagic (2004), Environmental Protection Agency - U.S. (2003), Fiksel, McDaniel and Mendenhall (1999), Global Reporting Initiative (2006), Hay and Noonan (2005), Institution of Chemical Engineers - IChemE (2002), International Standard Organization - ISO EN 14031 (1999), Labuschagne, Brent and Erck (2005), Olsthoorn et al. (2001), Schwarz, Beloff and Beaver (2002), Thoresen (1999), Velev and Ellenbecker (2001), Verein Deutscher Ingenieure - VDI (2006) and World Business Council for Sustainable Development - WBCSD (2000). Table I shows the environmental aspects and their possible performance indicators more frequently in accordance with these measurement systems.

Environmental aspect	Possible indicator of environmental performance
Materials	Quantity of material per product or quantity of material processed, recycled or reused.
Energy	Quantity of energy consumed per year, per product or quantity of energy saved by improvement programs.
Emissions	Quantity of specific emissions per year or per unit of product.
Water	Quantity of water discharged per unit of product or quantity of water consumed by product.
Noise and radiation	Quantity of warmth, vibration, light or noise emitted per unit of product.
Toxic materials	Amount of toxic waste controlled by permits or toxic waste eliminated by substitution of material.
Land use	Amount of land use or land affected, amount of land protected or restored.

Table I: Performance indicators identified at the literature related to environmental aspects.

According to Table 1, the vast majority of potential indicators is proposed for measuring the environmental performance of product units or the organization as a whole, and evaluated the set of all business processes, which may cause different biases on analysis of technologies which can be eco-efficient and, for example, entered in processes that have several losses of natural resources, or otherwise, which is strongly related to efficient management of technology.

One of the studies which come closest to this theme is presented by Labuschagne and Brent (2005). The authors propose the adoption of sustainability indicators in a given technology, implemented in industrial operations, by examining the life cycle and project life cycle process. The indicators are used in a particular way in the evaluation and selection of more sustainable technologies, as well as in the case reported by Jimenez-Gonzalez et al. (2001), who conducted experiments to determine the ranking of technologies greener compared different reactors that had been through a process of technology development. Note that, currently, these technologies have been developed and are with their performance settings determined, leaving only the option of choosing the one that presents the best performance in relation to natural resources consumed.

The preventive consideration, before or early in the technology development is neglected in the literature. There are important indications that the use of performance indica-

tors during the TDP may be an important tool for decision making in the adoption of more eco-efficient standards in new products and processes. An important aspect that has not received due attention by the literature on technology management. A step to understand it better is the analysis of theoretical models of technology development and conduct considerations on the use of eco-efficiency indicators at different times of TDP in order to anticipate the demands of eco-efficiency in products and processes through technology.

Technology development process

The technology development process can be defined as activities and decisions to convert knowledge and ideas into tangible artifacts, such as machinery, equipment and technology platforms, or intangible, such practical or process, that enable the necessary conditions for the development of products. The ordination of these activities and decisions required for this conversion constitutes a process of technology development, here referred to as TDP (Cooper, 2006; Kaplan and Tripsas, 2008; Sheasley, 2000).

One of the ways to improve the performance of TDP is the structuring of business process models, i.e., patterns of management practices and organizational structures that can help companies organize their innovation effort, similar to the literature product development. Another practice is to separate TDP to the product development process (PDP)

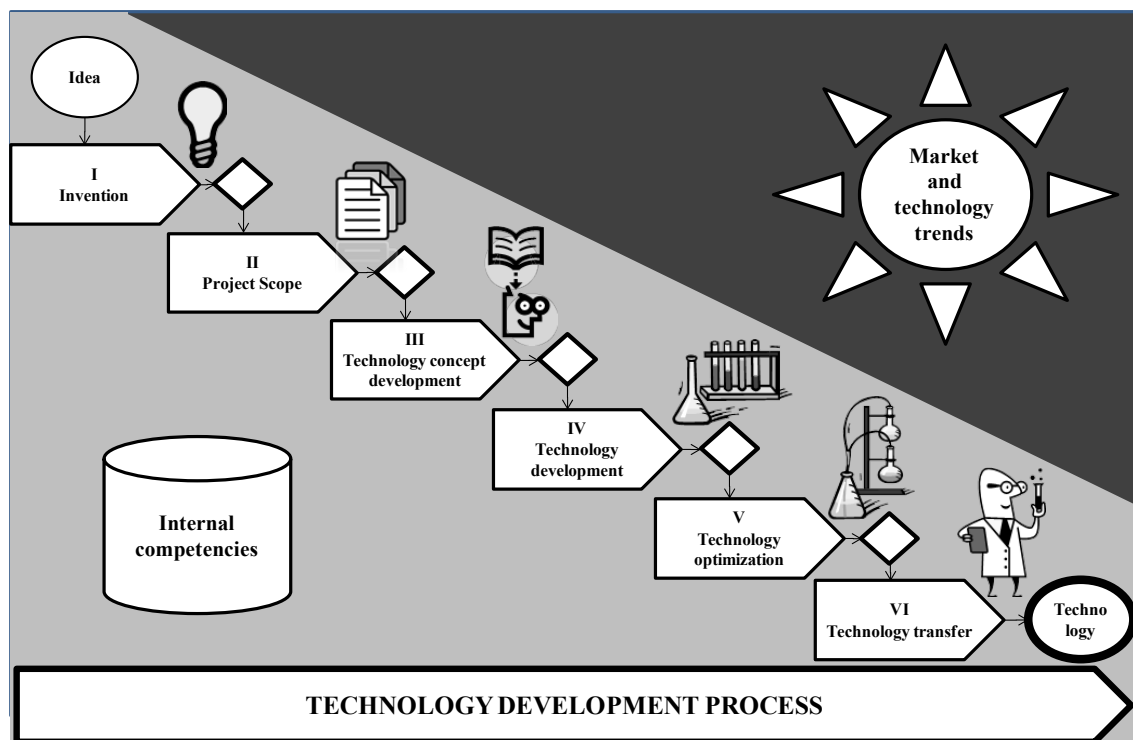


Figure 2: Stages and decision points of the theoretical model of TDP. Caetano, Araujo, Amaral and Guerrini (2011).

and to create models that help in efficient and effective implementation of these processes (Clark and Wheelwright, 1993). In this context, several prominent authors in the field of innovation and product development have proposed models of TDP, as Sheasley (2000), Clark and Wheelwright (1993), Clausing (1993), Cooper (2006) and Creveling et al. (2003).

At the Figure 2, Caetano, Araujo, Amaral and Guerrini (2011) propose a theoretical model of TDP with about 40 activities ranging from the definition of business strategy and technology strategy, identification of customer needs and new technologies, through the activities of developing and testing the technology itself to the criteria of its transfer to product development.

The TDP model presents at the Figure 2, oriented by the organizational internal competencies and the market and technology trends, contents the follow activities in each of the six stages:

I. Invention: define the enterprise' strategic planning, determining technology strategy, identify the voice of technology (basic and applied research), identify the voice of the consumer (market research), idea generation;

II. Project Scope: develop project scope, mapping future plans, conducting research literature, conduct patent searches, identifying opportunities;

III. Technology concept development: identify the potential of the idea under certain conditions by preliminary experiments, identify necessary resources and solutions to the gaps identified, designing product platforms, QFD to create a technology (technology needs), conduct benchmarking of available technology, develop network of partners, defining features of the new technology, identify the impact of technology in the company, analyze documents and generate technology concept;

IV. Technology development: select and develop concept of superior technology, define commercial products and pro-

cesses possible, decompose system functions into sub functions, define system architecture, use mathematical models that express the ideal function of technology, develop and test prototype, identify market impact and manufacture of these possibilities, prepare to implement the business case, identify and evaluate critical parameters;

V. Technology optimization: optimize technology from its critical parameters, analyze factors that may result in platforms, develop subsystems of the platform, implement and optimize experiments, analyze data from experiments;

VI. Technology transfer: design a platform, integrate the subsystems, performance testing of the system, define criteria for selection of technology (Caetano, Araujo, Amaral and Guerrini, 2011).

The TDP model contents activities that propose the use of mathematical models to demonstrate the ideals of the technology functions as well as an optimization stage of the technology. It is possible to note the deficiency about proposing activities related to environmental technology, such as identification of eco-efficiency technology, which could provide the base for decision making about the technologies to be developed with improved environmental performance. To further investigate this issue a research was conducted as described below.

Method

From a literature review on models available in literature about TDP (Brereton et al., 2007) are presented the activities that come from the idea generation up to the transfer of technology for product development. In parallel, it was performed a literature review of performance measurement models used by companies to assess the environmental sustainability of a product or technology. Subsequently, it was conducted a qualitative analysis of the activities proposed by the TDP literature (Bryman, 2006). This activity allowed the identification of different stages of the process could be enhanced by the use of indicators in order to support decision making in developing eco-efficient technologies.

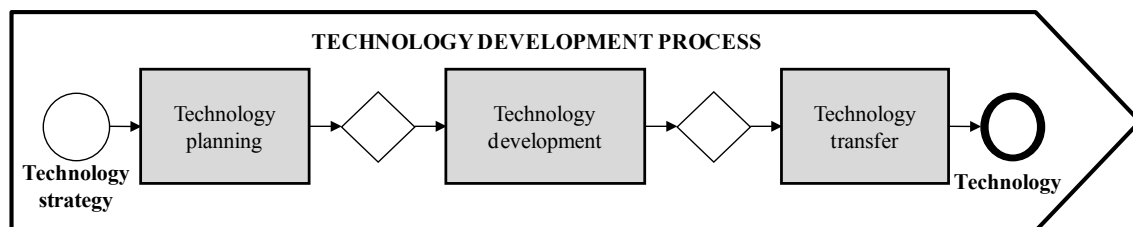


Figure 3. Schema with different stages proposed which can guide the use of eco-efficiency indicators.

The theoretical model of TDP was then divided into three different stages according to the groups of activities presented in the theoretical models. This division, presented schematically in Figure 3, was proposed by the authors to improve the understanding of the sequence of activities of the theoretical model of TDP. Although the names given to each of the moments as well as the number of stages is not the same in the model presented by Caetano, Araujo, Amaral and Guerrini (2011), it was chose to perform this grouping from an analysis of possible applications of this theoretical model from small and medium-sized technology-based companies.

The schematic model of TDP, shown in Figure 3, was synthesized and its stages divided among the following three points: the initial stage of technology planning, which can last about a month to be performed, an intermediate stage at the technology development, which can last years, and a final stage at the technology transfer, which can take some time to be integrated with product development (Cooper, 2006). These moments are interspersed with decision that determine whether the activities move forward or back in the TDP to conduct further investigations.

From a technology strategy focused on innovation, TDP begins with the activities of the technology planning, which includes stages I, II and III of the theoretical model of TDP, relating to invention, project scope and concept development, respectively. At this point is discussed the directions that the company should take in accordance with the needs of business, market and technology. Then, the technology concepts are generated in order to explore specific opportunities identified.

Approved the technology concepts, the activities are directed to the technology development, which comprises the stages IV and V, technology development and technology optimization, respectively, synthesized from the theoretical model of TDP. At this time are tested with prototypes and experiments that simulate actual conditions of use of this technology, which also conducted tests and adjustments in order to optimize the developed solution.

Finally, during the technology transfer, referring to stage VI of the same name in the theoretical model of TDP, the different subsystems are integrated into a larger system and defined the criteria for this technology is used in product development.

The description of TDP in this way could be developed from a theoretical analysis of inductive character and based on literature review, as a critical component for the development of research skills and understanding of the object of study (Karlsson, 2009). This distribution will, in the next section, a better argument about the possibilities of adopting eco-efficiency indicators in TDP.

The use of eco-efficiency indicator at the TDP

The main objective of the analysis was to determine whether the use of eco-efficiency indicators in these three different moments could improve the quality of decisions of the process, by increasing the assessment on eco-efficiency technologies in the TDP. This could be done by the P&D time during the different stages of technology development.

Utility	Description
Benchmarking	Compare process performance with similar characteristics to identify opportunities for improvement;
Traceability	The ability to measure progress over time;
Process evaluation	Indicators serve as an adequate support to decision making, serving for the selection of new production processes. Problems are identified before they become more complex;
Evaluation of Supply Chain	Individual values of processes can be summed to give the value corresponding to the entire supply chain. Thus, the processes with the greatest environmental impact within the supply chain can be identified;
Evaluation of facilities and technology	The indicators may be used preferentially to evaluate facilities and technologies;
Integration of different indicators	Indicators provide information that can be used in tools to support the decision integrated.

Table 2. Summary of possible management uses of eco-efficiency indicators.

The adoption of these indicators in the TDP can occur from different management uses, which are summarized in Table 2, adapted from Schwarz, Beloff and Beaver (2002), which can permeate throughout the TDP in the sense that the end result is really certified as eco-efficient.

In order to improve eco-efficiency analysis of a particular object, be it a product or technology, management uses in Table 2 are proposed in order to achieve the best possible performance in relation to natural resources (Ayres and Miller, 1980). In the case of technology, the determination of the managerial use of these indicators would be directly associated with the time it was in its development process.

During the moment of technology planning at the TDP a set of indicators could be useful to support an eco-efficiency strategy adopted by the company, establishing goals of consumption of natural resources that should be affected by technology. In this sense, these new technologies could be able to compete with existing technologies. These goals could be used like targets by the development team in anticipation of problems. Values targets for the indicators, to be met by technology that will begin to be developed, could be based on existing technologies, and would be used to demonstrate more clearly and unequivocally what the goals the development team would need to achieve. The result could be the reduction of wastage of resources and greater focus on developing components of eco-efficient technology. Indicators applied when the technology is planning could aid the projection of product platforms, which use similar technology with better eco-efficiency, enabling the development of various products without the need to develop new technologies at the new product development, reducing even the environmental impact caused by technology development (Robertson and Ulrich, 1998).

The adoption of partnerships for the development of technology could extend the aspect of eco-efficiency out of the company, because the partners could determine eco-efficiency metrics that should permeate throughout the project development, facilitating the formation of networks for sustainable innovation.

During the design of technology, indicators could be used to identify, through analysis of preliminary tests, which developing technologies would hardly achieve the goals determined. In this case, the team could decide to abort the project or searching for new solutions to the problem, avoiding unnecessary efforts and investments.

In addition, environmental drivers might guide the company's strategies to identify environmental trends of both production and consumption from environmental prospection.

The identification and translation of the voice of technology and the consumer could be construed as the voice of the future of society, or which technologies should be developed that would support, for example, clean production, considering the scarcity of certain natural resources and adopting ways to reduce waste, emissions of greenhouse gases, as well as increased recycling and reuse of natural resources without compromising future generations (Kaebernick, 2008).

For the moment of technology development, as Figure 3, the demonstration of eco-efficient technology could be identified during the course of experiments. The indicators demonstrate the levels of tolerance for the consumption of resources by the technology, as well as the desired performance and determining the critical parameters of the technology highlighted in the experiments. At this time, the activities of optimization experiments could be conducted in order to increase eco-efficiency technology through simulation of actual operating conditions for this technology. The indicators would thus contribute to the optimization of technology and detailing.

In the proposed by Jiménez-González et al. (2001) on the selection of certain technology to provide the best possible performance in terms of resources consumed, the authors focus only on the selection of technologies already developed, rather than its optimization during development. In this sense, could be conducted to develop systems of indicators that could relate to the technical parameters of technology performance with company performance and product marketing. This would be an important aspect to be questioned and developed by literature.

Finally, during the technology transfer, when the subsystems are integrated and the technology is validated, the indicators could provide limits and standards for certification and validation of the technology. Nemoto, Vasconcellos and Nelson (2010) complement this idea with a technological cooperation system to reduce the innovation risk, as well Jugend and Silva (2012) at the integration aspects of technology. This could help product developers to use the information generated in TDP and enforcement of the technology developed to check if they really planned targets for the technologies are seen in their performance. There would be a greater integration of the process in which the indicators planned at the beginning of the TDP to serve the ongoing verification process and, finally, for validation, diffusion of technology and determine new targets for future technologies.

Moreover, the criteria for choosing a technology may indicate several opportunities for the development of complementary technologies that also passes through a set of goals for eco-efficiency; this is developed internally or by some other partner to explore this opportunity.

Conclusion

The identification of specific moments during the technology development process, which deserves special attention by innovation managers, can become an important ally of the companies in the incorporation of environmental sustainability in the management of innovation through the use of eco-efficiency indicators.

It is a little explored area and requires several studies by researchers. In management theory of product development, there are no many tools or methods that help developers assess the performance of technology. The development of a method involving indicators could be useful, in particular, to assess various substitute technologies and help in choosing the most appropriate depending on the type of product being developed, anticipating the environmental impacts.

The analysis of this paper describes a gap that has not received much attention from researchers: the proposition of eco-efficiency indicators for use in TDP in order to develop eco-efficient technologies. It would be important to study the development of a system of indicators of eco-efficiency to support R&D, and this effort should begin in specific sectors such as technology development, and then be generalized to other functional areas of business.

It would also be of great value to insert "filters green" at the end of the TDP so that before the technology projects reached the stages of decision they would undergo a selection with respect to their environmental performance. The next steps for the implementation of these indicators would be the stratification of groups of indicators, as well as the elaboration of a ranking of those that should be considered in each specific stages of the TDP according to specific technologies, including the measurement of those indicators in the moment during the initial development goals, basing the technology planning, at the intermediate moment, during the technology development, as well as the final moment of the technology transfer, with a choice of more eco-efficient technologies to be used in product development, which would allow the management of innovation focused on the aspect of environmental sustainability in business.

The study identified several opportunities for the inclusion of indicators in order to contribute to the development of eco-efficiency technologies, and deserve to be explored by researchers. Besides exploring these issues, it is suggested that similar analysis and study of other indicators of sustainability that include the socio-economic and socio-environmental sense to propose a model that includes the sustainability in general at TDP.

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