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Scur, Gabriela; Marotti de Mello, Adriana; Schreiner, Lilian; das Neves, Fernando José
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Eco-design requirements in heavyweight vehicle development – a case study of the impact of the Euro 5 emissions standard on the Brazilian industry

Gabriela Scur
Centro Universitario da FEI, Sao Bernardo do Campo, Brazil

Adriana Marotti de Mello and Lilian Schreiner
Universidade de Sao Paulo, Sao Paulo, Brazil, and

Fernando José das Neves
Centro Universitario da FEI, Sao Bernardo do Campo, Brazil

Abstract

Purpose – The purpose of this paper is to investigate how technology-forcing regulations affect the product development process in the supply chain of heavyweight vehicles.

Design/methodology/approach – Through a case study, this paper seeks to understand how one of the leading companies in heavyweight vehicles manufacturing industry and its engine supplier in Brazil introduce eco-design practices into its engine development process.

Findings – Through case studies conducted in a heavyweight vehicle producer and its engine supplier, this study shows that, in addition to meeting the standards and legislation, the automaker uses ecodesign practices during the product development cycle such as a design that eliminates harmful and hazardous materials and a project that allows recycling, the reuse of parts and energy efficiency, thereby reducing the environmental impact. However, without the mandatory requirements imposed by federal legislation, products with lower environmental impacts would rarely be developed, as environmental performance is not demanded by customers, who are mainly cost driven. Technology-forcing regulations play an important role in enhancing the adoption of ecodesign practices, but market and competitive conditions also play an important role.

Originality/value – Several studies on the impacts of public policies and development for the automobile sector have been conducted, but there is a lack of studies in the area of commercial vehicles, especially in Brazil. Therefore, this research is justified by new demands of society, in addition to the necessity of complying with legal requirements and the adoption of good practices related to eco-design.

Keywords Automotive industry, Product development, Ecodesign, Heavyweight vehicles

Paper type Research paper

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1. Introduction

It is widely known that the traditional production and consumption model and economic interest do not usually converge with environmental commitment. Ceschin and Vezzoli (2010) argue that the automotive industry is economically interested in reducing its energy and material consumption in production because it aims to reduce manufacturing costs, but at the same time, it does not have a direct economic interest in reducing energy consumption when the vehicle is in use or in extending the vehicle's life span. Meanwhile, automobiles have a high impact on the environment and society, especially through their use: air pollution and traffic congestion are two major negative impacts (Farkavcova, Rieckhof, & Guenther, 2018).

In recent decades, growing pressure from society has led governments worldwide to adopt stricter policies regarding emissions, especially in the form of technology-forcing regulations (Wesseling, Farla, & Hekkert, 2015).

To comply with these regulations, companies need to integrate solutions to environmental issues into their products and processes to gain and maintain market share. Environmental issues and the expansion of the supply chain scope have played a significant role in the development of company's competitive strategies in this context (Govindan, Kaliyan, Kannan, & Haq, 2014; Hsu, Choon Tan, Hanim Mohamad Zailani, & Jayaraman, 2013; Jullien, 2008). Concepts such as ecodesign have promoted a reinterpretation of the conception, design, and the industrial production of goods (Byggeth, Broman, & Robèrt, 2007), providing a theoretical framework for application guidelines in the product development process. There is a robust body of literature that relates product project and environmental issues, covering aspects such as decision design (Romli, Prickett, Setchi, & Soe, 2015), product design tools (Donnelly, Beckett-Furnell, Traeger, Okrasinski, & Holman, 2006), and product development in the automotive industry (Schoggl, Baumgartner, & Hofer, 2017). However, there are fewer studies specifically regarding technology-forcing regulations and product design for the heavyweight vehicle industry. Most studies regarding heavyweight vehicles, such as Farkavcova *et al.* (2018), address issues in the use of vehicles, such as logistics and transportation.

Therefore, the aim of this paper is to investigate how technology-forcing regulations affect the product development process in the supply chain of heavyweight vehicles. Unlike cars, heavyweight (commercial) vehicles are capital goods: they represent an investment for their customers (transportation companies or independent truckers), who are sensitive to cost and less sensitive to environmental issues (Wollmann, 2018).

The choice of the sector stems from the high concern within urban societies regarding the environmental impacts resulting from the gas emissions of diesel-powered heavyweight vehicles, especially after the so-called "Dieselgate" scandal[1].

In 1986, the Brazilian federal government established the PROCONVE (Control Program for Air Pollution by Motor Vehicles), a program that aims to control and progressively reduce the gas emissions of passenger cars, trucks and busses[2].

In 2012, the 7th step of PROCONVE was launched. To meet the new emission standards for CO and other gases in Brazil, the industry launched the Euro 5 generation of engines, which required new investments in product development in different stages of the automotive supply chain. In addition, several studies on the impacts of public policies and development for the automobile sector have been conducted, but there is a lack of studies in the area of commercial vehicles, especially in Brazil.

This paper is structured into five main sections. In Section 2, we review the literature by discussing environmental regulations and the concept of ecodesign. Then, we discuss how ecodesign is integrated into the automotive industry. In Section 3, in the methods, we describe the case research strategy and the procedures for data collection and analysis. In Section 4, we present the cases of the two companies studied and conduct a comparison with the literature, based upon which we develop our conclusions. Finally, in Section 5, we conclude the paper by discussing final considerations.

2. Theoretical foundation

2.1 Ecodesign

The concept of sustainability combines concern for the planet's well-being with recognition of the growth and development of humanity, i.e. sustainability means meeting current needs without compromising the ability of future generations to meet their own needs. Design for the environment, green design, ecological design or ecodesign, and design for sustainability comprise design models driven by ecological criteria and represent the combination of design activity and consideration of the environment.

The concept of green product design emerged in the late 1990s, when the US electronics industry sought to minimize the impact on the environment caused by its activities. Currently, business models must consider consumers both as individuals with complex needs and as members of a large community with complex interdependencies; further, they must consider the communities of tomorrow, which will be affected by our current decisions and behaviors. This new business model requires sustainable innovations or eco-innovations (Boons, Montalvo, Quist, & Wagner, 2013; Boons & Lüdeke-Freund, 2013; Esslinger, 2011). According to sustainable thinking, tools are emerging for sustainable innovation, such as design for the environment and life-cycle assessment (LCA), which should be used as needed to relate design to the environmental sustainability of products (Eppinger, 2011), and ecodesign, which requires awareness of both the short-term and long-term consequences of any transformation in the environment. Furthermore, ecodesign should be economically viable, i.e. create a product that is ecologically sound and competitive in the market, with minimized impact on the environment, and with measurable environmental quality (White, Belletire, & Pierre, 2004).

Green design and ecodesign are terms that have been widely used in the literature to specify products that meet environmental requirements. The number of green products has grown rapidly, as demonstrated by the growing number of companies requesting certification labels for their eco-friendly products. For example, the number of companies with the European Eco-label rose from 50 at the end of 2000 to over 1000 in 2010 (Dangelico, Pontrandolfo, & Pujari, 2013).

Thus, ecodesign is a proactive approach to environmental management that integrates environmental issues into product development and its respective process without compromising functionality, performance, quality or cost (Pigosso, Rozenfeld, & McAloone, 2013);

Additionally, ecodesign refers to the actions taken during product development to minimize the product's environmental impact throughout its life cycle – from the procurement of materials, to manufacturing, to the product's use, and ultimately, to its final disposal – without compromising other essential criteria of the product, such as performance and cost (Ulrich & Eppinger, 2007; Zhu, Sarkis, & Lai, 2008).

The basic activities of ecodesign include the following:

- design for reducing or eliminating environmentally hazardous materials such as lead, mercury, chromium, and cadmium (Moreira, 2002);
- design for reuse facilitates the reuse of a product, or of a part thereof, with or without a minimal treatment of the used product (Gupta & Palsule-Desai, 2001);

- design for recycling facilitates the dismantling of the product, the separation of parts according to the material, and material reprocessing (Hall, 2001);
- design for remanufacturing facilitates repair, rework, and renovation activities, with the aim of making the product new or in an improved condition (Beamon, 1999); and
- design for resource efficiency, including reducing the materials and energy consumption of a product during use (Sarkis, 2001).

Among the challenges of implementation affecting the success of this approach is communication between the actors belonging to a particular value chain and aiming to make it a sustainable network. In this network, everyone knows the sustainability impacts that their products offer, from raw material to disposal, extending through production and packaging (Dangelico *et al.*, 2013; Eppinger, 2011; Lenox & Ehrenfeld, 1997).

Products should be designed to provide a certain level of durability for the consumer within a commercially viable and acceptable period. Developing a product for infinite life when it is not needed often results in wasted resources, in addition to resulting in waste that is difficult to recycle because more durable and less biodegradable materials have been used. Another recommendation is to develop products to meet the exact expected loading and capacity, without exceeding these requirements, to reduce or eliminate wasted materials and natural resources (Chiodo, 2005).

2.2 Ecodesign and the automotive industry

For the automotive industry, new product concepts and new forms of designing are part of the technological innovation process, driven by the binary "product quality x the environment", which is located at the core of global automakers' strategies. Innovation is required for cleaner production, using fewer pollutants and more recyclable materials and better processes. Moreover, environmental performance needs to be analyzed throughout the product life cycle (Farkavcova *et al.*, 2018; Gonzales, Alvarez, & Anderson, 2010).

According to Rocha *et al.* (2011), in general, companies invest in ecodesign to at least meet, or potentially improve upon, the following:

- government policies, legislation and standardization;
- the company's environmental policy and environmental management systems;
- the social environment;
- product innovation and differentiation;
- increased product quality;
- product cost reduction;
- available technologies;
- the company's image;
- customer requirements;
- trends; and
- the challenge of a new design and workers' motivation.

These motivating factors may arise from the business itself or from the external environment.

Compliance with legal requirements is an important factor motivating the adoption of ecodesign practices. Elmquist and Segrestin (2009) argue that regulation is pushing manufacturers to reduce environmental impacts, such as CO_2 emissions. Ceschin and

Vezzoli (2010) state that governments should intervene to orient the market in a direction that could bring benefits to society. Moreover, the need for government intervention can be justified by the externalities. Externalities are environmental impacts that are not included in the market price; e.g. the environmental and health costs related to the use of diesel are not included in the price of either diesel or the diesel truck. Thus, manufacturers are not motivated to consider the effects of using their products.

LCA offers a method of assessing the environmental impacts of a product or service associated with its total life cycle. Although it requires extensive data collection and data sharing among different enterprises using different data representations, LCA is increasingly being used as a management tool to embed environmental concern into product development (Gmelin & Seuring, 2014).

2.3 Technology-forcing regulations in the auto industry

In recent decades, growing pressure from society has led governments worldwide to adopt stricter policies regarding emissions, especially in the form of technology-forcing regulations. This type of regulation is adopted by policy to simulate eco-innovation and thereby reduce pollution, prevent the degradation of natural resources, incentivize research and development, and remove information asymmetries between key players in the market (Doran & Ryan, 2012; Wesseling *et al.*, 2015). Porter, in a seminal article from 1991, argues, "Strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it" (Porter, 1991, p. 168).

However, after three decades, there is still great controversy surrounding this statement, and many companies remain skeptical about adopting eco-innovations. Ambec, Coheny, Elgiez, and Lanoie (2013) observe that results of environmental regulations are not totally positive: many regulations increase costs and lead to conservative behavior from firms. These contrary results may be explained by the fact that firm, industry or environmental characteristics could affect the extent to which innovation offsets and productivity or competitive enhancements occur.

Oltra and Saint Jean (2009) discussed this behavior in the auto industry and concluded that the existing literature on environmental innovations neglects the interdependencies between environmental innovations and the industrial dynamics of sectors: environmental innovations may be a response to regulatory pressures, but they must also meet firm objectives in terms of competitiveness and demand. Therefore, the market and product competitiveness will also play an important role in the success (or failure) of environmental regulations.

In the auto industry, regulations that specify the maximum limits for CO and HC in vehicle emissions began in the 1960s and 1970s in the USA, Japan and Europe. Since then, emissions standards have been a continuous topic of discussion and have become stricter, demanding the development of technological solutions from the auto industry. Although there are some drawbacks, the overall assessment is that these regulations have led to a higher level of competitiveness and innovation despite initial higher costs (Franckx, 2015)

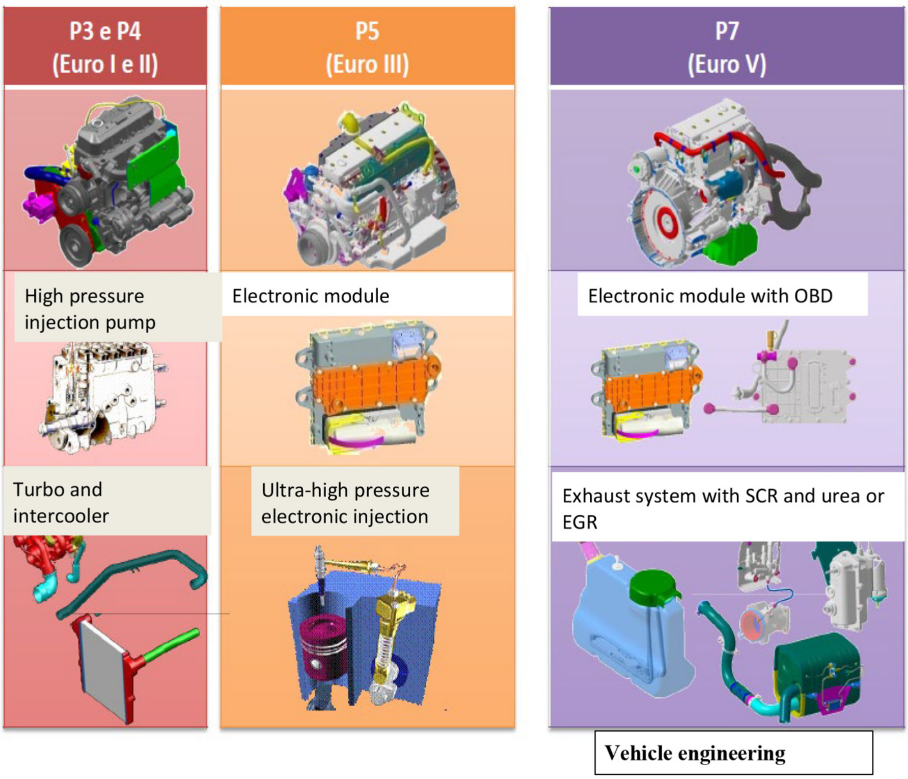
2.3.1 Technology-forcing regulations for heavyweight vehicles in Brazil – PROCONVE 7 and the Euro 5 standards. In 1986, Brazil adopted a program called PROCONVE (Control Program for Air Pollution by Motor Vehicles) to limit gas emissions from internal combustion engines. This program aims to reduce the environmental impact of internal combustion vehicles in terms of both air quality and noise by creating a progressive set of emission restrictions based on European standards. The 7th phase of PROCONVE for trucks (PROCONVE 7) comprises the adoption by legislation of the Euro 5 emissions levels. This new legislation mandate entered into force in 2012, and all truck-type vehicles and busses with diesel engines leaving Brazilian factories should follow the specifications or emissions limits established in the Euro 5 standards.

Figure 1 shows the evolution of diesel engines in terms of their emissions levels and changes in technology and design. In less than a decade, the technology has shifted from conventional engines to engines with electronic modules and a urea injection system to wash the exhaust system gases and thereby achieve the atmospheric emissions levels proposed in Euro 5.

Investments in design were beyond the boundaries of the automakers, given that an entire chain of supplies and infrastructure was involved in product development such as engine, electronic module (OBD) and exhaust system (SCR) suppliers; gas station adequacy; Petrobras (Brazilian oil company) infrastructure for the production of diesel S50, which reflects the improvement of diesel quality (reduction in sulfur levels from 1800 to 50 ppm); and Arla 32 (urea) production and distribution[3].

There were several delays in the production and launch schedule, both from automakers and Petrobras. Euro 5 standards were only mandatory after 2012, instead of the initially estimated date of 2009, and only following intervention by the Federal Justice (Anfavea, 2009).

Heavyweight vehicle producers claimed that production costs were higher, and because of this, they launched Euro 5 trucks in markets with higher prices.



Source: Anfavea (2014)

Figure 1. Technological evolution from the PROCONVE resolutions

Given this information in advance, fleet owners anticipated the purchase of trucks and busses, with a consequent drop in the market in 2012 and 2013. This strategy caused a delay in the substitution of the fleet – which was worsened by the economic crisis that affected Brazil starting 2014. Altogether, these factors have lowered the adoption of Euro 5 engines in the market. To highlight this, see Figure 2 for the evolution of the truck fleet meeting PROCONVE 7 standards in São Paulo state (the largest market in Brazil). In 2015, 76 per cent of the fleet was estimated to have higher emissions standards (Euro 3 or lower) (Bales, 2016).

In addition to these obstacles, air quality, especially regarding SO_2 concentration, is declining, as shown in Figure 3.

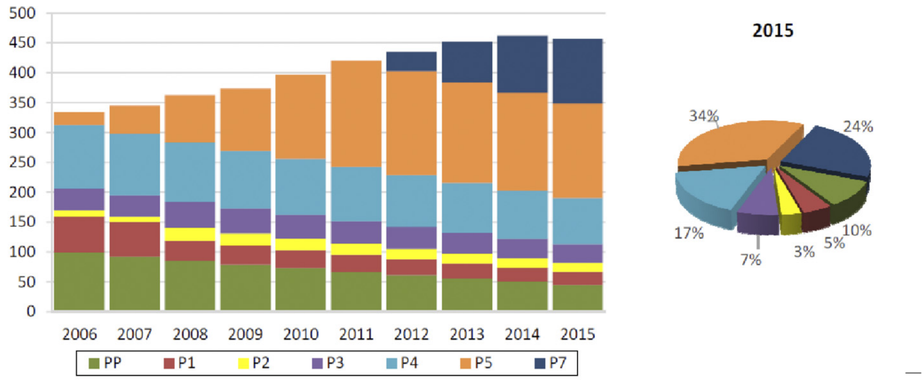


Figure 2. Heavyweight vehicle fleet evolution according the PROCONVE standards in the state of São Paulo

Source: Bales, (2016)

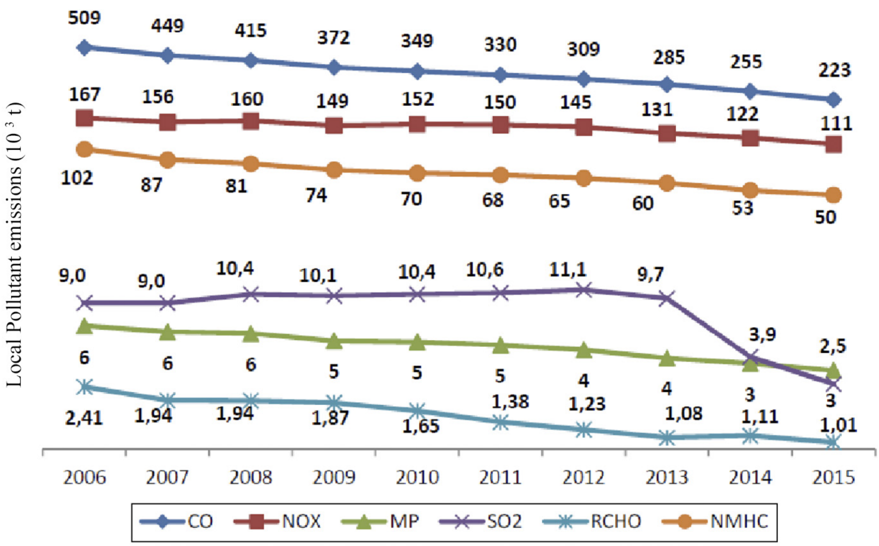


Figure 3. Pollutant concentration evolution in state of São Paulo – 2006-2015

Source: Bales, (2016)

2.4 Environmental impact of the heavyweight vehicle industry

In recent decades, the automotive industry has faced many challenges related to the issue of sustainability. From an environmental perspective, it has been held responsible for the deterioration of air quality, global warming, and the generation of waste at the end of life, for example. In addition, there are economic challenges from fierce global competition, the rising costs of raw materials, and a constant reduction in profit margins (Van Hoek, 2001).

In the manufacturing area, starting in the 1980s, significant improvement has been observed in the environmental sustainability of manufacturing processes, primarily driven by pressure to reduce costs. These pressures led to the adoption of measures to rationalize the use of materials and energy, which reduced waste, increased productivity and thereby benefitted the environment. Orsato and Wells (2007) summarize the context of the environmental, economic, and operational challenges facing the automotive industry. They explain that automakers are stuck in three technological paradigms (all-steel vehicle bodies, internal combustion engines and multipurpose vehicles); thus, these companies tend to favor incremental improvements. Moreover, the current economic and political interdependence between this industry and other sectors (e.g. the oil industry) increases the difficulty of implementing radical changes towards higher performance levels in the environment.

For the automotive industry, the greatest environmental impacts occur after the production and during the use of the vehicle (Mildenberger & Khare, 2000), though there are also environmental problems with the production and final disposal of vehicles. The use of vehicles consumes a significant amount of fossil fuels and is thus an important source of pollution (Mildenberger & Khare, 2000).

The harmful emissions from the exhaust systems of diesel-powered heavyweight vehicles include carbon dioxide, carbon monoxide, sulfur, nitrogen oxides, particulate matter, ozone, aldehydes composed of hydrocarbons and particulates. During their production, the main environmental impacts result from solid waste generation, the emissions of volatile organic compounds, and high levels of energy and water consumption. In addition, at the end of its life cycle, the vehicle can contaminate the soil and groundwater if there is inadequate management of landfills (Nunes & Bennett, 2008).

The interaction between the project or design, production, use, and disposal of vehicles leads to complexity and difficulties in making environmental decisions. For example, reducing the vehicles' weight is one technique for reducing fuel consumption during use; this is normally done by substituting steel parts with plastic and aluminum composite materials. However, this technique increases the difficulty in disassembly and lowers the commercial value of vehicle waste; thus, it negatively affects the recycling of vehicles at the end of life (Van Hoek, 2001).

To understand the relationship between the automotive industry and the environment, Table I presents the main environmental aspects and impacts of the activities in this sector along with a basic assessment based on the suggestions of ISO 14004.

2.5 Conceptual framework

Based on the aforementioned considerations, we intend to deepen understanding regarding how technology-forcing regulations affect the product development process in the heavyweight vehicle supply chain.

Vehicles have the highest environmental impact after production and during use of the product; this is caused by harmful emissions from exhaust systems, which is especially critical for diesel-powered engines (Mildenberger & Khare, 2000). For this reason, most environmental regulations aim to reduce emissions, such as the PROCONVE mandate in Brazil.

Activities	Environmental aspects	Environmental impacts	Category	Type
Production, Buildings Construction and Operations	Land, water and energy use and materials consumption	Depletion of natural resources and pollution	Local regional global	Negative
Manufacture	Emissions of harmful substances. Water, energy and materials consumption	Depletion of natural resources and pollution	Local regional global	Negative
Logistics	Ships Air Highways	Air and sea pollution, and traffic congestion	Local regional global	Negative
Job offers	Employments	Improvement of people's quality of life	Local/regional	Positive
Economic Contribution	Trade of goods and services	Capital and people flow, fulfilled needs	Local regional global	Positive
Infrastructure use	Highways, parking lots, spaces, bridges	Depletion of natural resources	Local regional	Negative
Fuel combustion	Air emissions	Air pollution	Local regional global	Negative
Mobility	Mobility of people and goods	Congestion and accidents	Local	Negative
End of life storage, dismantling, reuse, remanufacturing and recycling	Reuse of materials	Reduction in the depletion of natural resources and pollution	Regional	Positive
Disposal after the end of life	Disposal in landfill	Depletion of natural resources and soil contamination	Regional	Negative

Source: Adapted from Van Hoek (2001)

Table I. Environmental aspects and impacts in the automotive industry

However, according to the literature (Ambec *et al.*, 2013; Franckx, 2015), the success of technology-forcing regulations also depends upon industry competitiveness and demand objectives.

In this research, we intend to discuss how the PROCONVE standards have affected product development processes in the heavyweight vehicle industry in Brazil.

Based on the literature reviewed in Section 2.1, we developed a conceptual framework for our research, which is presented in Table II. This conceptual framework serves as the basis for the empirical research and guides data selection and analysis. We intend to verify the heavyweight vehicles industry's approach to adopting ecodesign practices after the PROCONVE/Euro 5 mandate.

3. Methodological procedures

A qualitative approach was taken to understand how environmental regulations affected the product development process of one of the leading companies in the heavyweight vehicle manufacturing industry in Brazil. The case study method is used to investigate a specific phenomenon within a given context or a context that is not sufficiently elucidated (Yin, 2005). According to Eisenhardt (1989), the case study is a research strategy that focuses on understanding the dynamics present within unique configurations. In addition to the interviews, this case study combined other data collection methods, such as examining

Concept/ construct	Dimensions
Ecodesign	Design for reducing or eliminating environmentally hazardous materials Design for reuse that facilitates the reuse of the product or parts thereof, with or without a minimal treatment of the used product Design for recycling, a project that facilitates the dismantling of the product, the separation of parts according to the material and reprocessing Design for remanufacturing, design that facilitates the repair, rework and renovation activities, aiming at making the product new or in an improved condition Design for resource efficiency, including reducing materials and energy consumption during the use of the product Process development considering impacts on the environment (natural resource consumption and generation of solid waste, liquid effluents, atmospheric emissions, etc.) Product development motivated by compliance with norms, laws and resolutions Development of ecologically efficient products to gain market share or increase sales (company's motivation as marketing strategy)

Table II. Conceptual framework

documentation represented by the technical design, the bill of materials used in the design, emissions, organizational records, drawings, parts lists, internal standards, procedures for product development, personal notes and participant observations.

Furthermore, the research also includes participant observations because one of the researchers has worked for 11 years in the truck manufacturing industry as a manufacturing engineering coordinator. Participant observation is commonly linked to the data collection phase, but it cannot be resumed on this. Participant observation can be defined as the process of observing a community or social group where the researcher assumes a role in this unit of analysis to share experiences (Bernard, 2017). All of these sources of information enabled data triangulation, combination and analysis to support the findings (Eisenhardt, 1989).

Interviews were conducted to understand how ecodesign practices were adopted in the heavyweight vehicles industry in the beginning of 2015; these focused on the latest launch of this company, which were trucks equipped with Euro 5 engines. The automaker does not produce its own engine to equip the trucks but instead buys engines from a first-tier supplier. Thus, the research was conducted on two levels: at the truck automaker (the focal company) and at the engine manufacturer.

The interviewee's profile was first as a person who was personally involved in product development or related activities, had knowledge and experience in the function, and preferably had some authority on the subject. In addition, to avoid the risk of potentially inhibiting responses given the function performed by the respondents, only those with executive positions at different levels of the hierarchy (sequentially in ascending hierarchical order, managers, senior managers and directors) and for different areas of responsibility were interviewed: product development, environmental engineering and supply chain. We invited ten employees from the two firms and six agreed to participate in the research (Table III).

Respondents were interviewed based on a script consisting of semistructured questions to identify the maturity of ecodesign in these companies (Appendix).

During the interviews, notes were taken of the documents presented and the respondents' answers, and when possible, the interviews were recorded. However, as the research focuses on the development of products in which a great deal of information is

Company	Company description	Respondent	Data collection	Data, files and/or evidence
A	Multinational manufacturer of commercial vehicles and trucks	Coordinator of Product Development Coordinator of Environmental Engineering	Visits to the plant with over 12 hours of interviews	Company information and documents on sustainability, environmental policy, mission and goals. Intranet data and PowerPoint documents on product development.
		Coordinator supply chain		Rules and procedures on the intranet
B	Multinational company, manufacturer of truck engines	Manager of Product Development	Visits to the plant with over 4 h of interviews	Presentations on product development on the intranet.
		Senior Manager of Environmental Engineering Manager of Supply Chain		Rules and procedures on the intranet

Table III.
Data collection

strategic, both companies requested that secrecy of the information be preserved and their names be concealed.

4. Results

The automaker and its engine supplier have taken actions to adopt certain environmental practices, including internal environmental management and investment recovery. Some actions that fall under internal environmental management are the ISO 14001 certification and the establishment of environmental goals for the factory, such as reducing energy and water consumption and the generation of CO_2 and waste. Investment recovery mainly occurs through the sale of scrap and used materials to recycling companies.

Regarding product development, both the truck automaker (called A) and the engine manufacturer (called B) have their own centers for this purpose; however, because they are multinational companies, most of the quality and performance requirements are standardized by the matrices, with the exception of local legal requirements.

Regarding the development design of the engine with Euro 5 technology for trucks, this was a joint effort between the engineering staff of companies A and B, in which company A was the client and B the provider.

The product development model adopted by the automaker consists of the following three phases: pre-development, development and post-development.

In the predevelopment phase, the ideas to meet the raised requirements are generated and gathered, restrictions on each idea are evaluated, and the most relevant ideas are prioritized. The main objective is to reach the end of this phase with a defined project portfolio, with the restrictions already considered, that properly aligns with the corporation's strategic plan and its goals.

After defining the projects to be developed, the development phase starts. This phase is divided into five stages. The first is informational design and consists of collecting information for the development of the projects and defining the teams and resources. In the conceptual phase, the concepts for meeting the requirements and specifications are defined. In the detailed design phase, all drawings, prototypes, and tests are be developed and completed, resulting in the ratification of the product. In the stage of preparing for production, production processes should be detailed and machines should be specified, purchased, and installed. In the launch phase, production starts, and the product is launched in the market.

At the end of each phase, the quality of the results up to that moment is verified. This verification is known as the transition phase, and it represents a reflection upon the progress of the project in relation to the planning, scope, deadlines, costs, and problems. At this point, the indicators set for the project are analyzed and compared to the established goals, and if problems are identified, the change management committee may require changes or may decide to restart the phase.

The development of this engine was performed in a two-year cycle that followed the process shown in Figure 4, which shows the total time spent on engine development and the steps that guided the evolution of the development phases of this product.

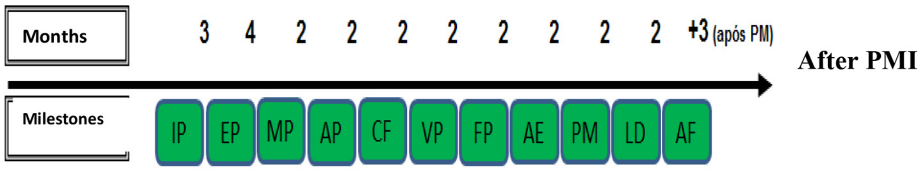
Table IV shows the main activities related to ecodesign practices during the development of the Euro 5 engine.

Regarding the *design for eliminating or reducing environmentally hazardous materials*, automotive manufacturers have restricted the use of these substances. Both company A and company B have lists of substances that are explicitly prohibited for any type of use and substances that can be used but only in restricted quantities.

The suppliers serving the automaker should issue a statement confirming that their products meet regulatory restrictions. Companies maintain an updated database called the international material data system, which has records on all automotive parts and their chemical compositions.

There is no *design for reuse* step because the parts and components have specific functions and applications, and reuse is not recommended.

One ecodesign practice is *design for recycling*. This occurs in the early stages of the project, where parts are selected consisting of materials that allow recycling, and in the phases in which the vehicle goes through the assembly line for testing. The packaging of parts for mounting the engine in the vehicle was developed by company A to be returnable



Notes: where *IP* – Project start: Define strategy, mission, and alignment with marketing; *EP* – Project strategy: Program compatibility or development with strategy, marketing, finance, quality and product development; *MP* – Project goals: Definition of goals and preparation of indicators for the project; *AP* – Project approval: Approval of funding and resources for the project; *CF* – Confirmation of tooling: Start of tooling and orders to suppliers to manufacture parts for the prototype; *VP* – Prototype vehicle: Manufacture of the prototype vehicle; *FP* – Fabrication of the preliminary lot: Approval for the fabrication of parts and tests of tools and virtual assembling; *AE* – Approval of style: Approval for the design, color, and materials to be used and dimensions; *PM* – Mass production: Approval for mass production; *LD* – Release for sale and distribution: Authorization for the sale of vehicles based on an analysis of the developed products; and *AF* – Final evaluation: Final evaluation of product development and final review of the indicators

Figure 4. Timeline for product development

Ecodesign practices	Company A	Company B
Design for reducing or eliminating environmentally hazardous materials	Compliance with headquarters rules about hazardous materials. Occurs during product conception	Compliance with Company A's (client) regulations and internal rules. Occurs during product conception
Design for reuse	No evidence for this practice. Euro 5 engine is not suitable for reuse	No evidence for this practice. Euro 5 engine is not suitable for reuse
Design for recycle	Plastics and metals are recyclable. Occurs during product conception and during try-outs, when parts packaging is developed	Compliance with Company A's (client) regulations and internal rules
Design for remanufacturing	Euro 5 design should facilitate access for repair according to service department	Compliance with Company A rules. Developed in the beginning of the project and during the functional and driving tests
Design for resource efficiency	Fuel consumption goals defined. This is a project KPI, because it is an important competitive argument	Based on Company A's specifications and market analysis
Development of processes considering impacts generated on the environment	Considered throughout the project	Compliance with company A's rules
Development of products motivated by compliance with norms, laws and resolutions	This was the main motivation for the project. Engine is more expensive and has a higher maintenance cost	Compliance with company A's rules
Development of ecologically efficient products to gain market share or increase sales	It was the opposite. Initially, market rejected the change to Euro 5 due to the higher price	The main driver is to follow legal requirements

Table IV. Identification of ecodesign practices adopted by the surveyed companies

to company B, reducing the disposal of wood and plastic. There are goals in the project scorecard that guide engineers in obtaining product recycling rates, as shown in Table V.

Companies A and B state in their indicators that 98 per cent of the Euro 5 engine is recyclable.

There are actions for *remanufacturing* by both company A and company B. The automaker was concerned with the interaction between the engine and the vehicle, i.e. in an occasional failure of the engine or its components, access to these parts should be quick and easy. The engine supplier was concerned about access and ease of repair with regard to the engine and its internal parts. This evaluation was performed at the beginning of the project by product development engineers and by the service team that performs simulations of

Environmental goals	Definition of the green scorecard
Hazardous materials	Absence of hazardous materials
Recyclability	Equal or higher than 90% of materials used
Emissions level	Follow PROCONVE 7 rules
Fuel consumption	Equal or 5% less than the previous generation

Table V. Scorecard of environmental requirements changes and repairs because it is responsible for writing the vehicle's manual and for training the dealer network.

During the presentation of the prototype and preliminary training of the dealer network, ideas and improvement opportunities arise, which provide feedback for product engineering. Manufacturing from the try-out phases at the factory to mass production also uncovers design improvement opportunities to facilitate disassembly and possible repairs.

Design for resource efficiency is a key factor in obtaining requests because a more efficient truck from an energy perspective has a lower use cost. Therefore, at least a 5 per cent goal should be set to reduce the km/l consumption of diesel fuel, which was achieved by the automaker in this project.

Regarding the *development of products to reduce environmental impacts*, the automaker has internal indicators that monitor the water consumption per produced vehicle, the electricity consumption per produced vehicle, and compliance with environmental standards on a monthly basis. All new projects have the goal of not undermining the indicators of the current vehicle, i.e. the new vehicle must maintain or improve the plant indicators when it is launched.

The scorecard indicated a 10 per cent reduction in MWh/vehicle and a 3 per cent reduction in M^3water/vehicle over the past three years, and the implementation of new processes for fabricating the vehicle with the Euro 5 engine sustained this indicator and maintained it with a positive trend.

The evolution of these indicators demonstrates the implementation of new processes that promote a lower environmental impact for each of the automaker's projects.

5. Conclusions

This article aims to analyze how environmental regulations affected the product development process of one of the leading companies in the heavyweight vehicle manufacturing industry in Brazil. As a study object, ecodesign practices were verified during the development of trucks with the euro 5 engine.

Some ecodesign practices could be verified at various product development stages at the studied companies, but mainly at the automaker because it imposes the conditions and norms for product development.

However, attention should be paid to the fact that the project was mainly motivated by the existence of governmental regulation. Although the engine supplier already possessed the technology needed to develop this product (and had already offered it in other markets), the "euro 5" truck was only commercially launched after the government's decision.

Ecodesign factors that are beneficial from an economic perspective – such as greater efficiency in the use of fuel by the user, ease of maintenance (remanufacturing), greater efficiency in the production process, and waste reduction – are more easily assimilated. Innovation that aims at improving the environmental performance of the process, and mainly of the product, is still incremental in the industry, especially in the heavyweight vehicles segment.

More radical innovations, such as the use of engines that are more efficient or produce fewer emissions – such as those powered by biofuels or even hybrid and electric engines – are still far from the market. Our conclusion is that companies are reluctant to adopt environmental innovations, and they do so only to follow governmental regulations. Therefore, technology-forcing regulations play an important role in enhancing the adoption of ecodesign practices, but market and competitive conditions also play an important role, especially regarding product diffusion. It is important to emphasize that the ecological appeal is still very limited with regard to the motivation for the purchase of trucks. As an equity investment, the major decision factor is the economic performance of the vehicle, as opposed to buying a car, where the emotional factor is more relevant. After the entry into force of PROCONVE 7, sales of trucks have fallen because many consumers advanced the exchange of their trucks with Euro 3 models.

Therefore, the "pressure by aware consumers" on design decisions has a very limited range, and in this case, government regulations are fundamental.

Thus, this article concludes that in the heavyweight vehicle industry (and possibly in other capital goods segments), customer and other stakeholder pressures are not the main driver for the adoption and diffusion of eco-innovations. Regulations and incentives from governments are fundamental for the successful diffusion of ecodesign practices, although practices that can be easily directed toward financial results (such as reduction in fuel consumption, process waste and energy or water consumption) are more likely to be adopted by companies without any formal regulation.

In addition to its contributions, this article has some limitations. The main limitation, inherent in the research method used, is the impossibility of generalizing the conclusions. Nonetheless, from the evidence found in the Brazilian subsidiary of a heavyweight automotive manufacturer, a hypothesis and future research plans can be derived for industrial sectors with similar characteristics, such as the capital goods sector. Additional research by incorporating other actors in addition to automotive supply chain companies, such as the main consumers and public agents, is also suggested.

Notes

1. "Dieselgate" is the popular name given to the VW emissions scandal. In 2015, VW admitted that it has installed a device in diesel engines to mislead emission tests. https://knowledge.wharton.upenn.edu/article/volkswagen-diesel-scandal/
2. For more detail about the PROCONVE program, see www.ibama.gov.br/areas-tematicas-qa/programa-proconve
3. Source: Petrobras (Brazilian Oil Company) www.br.com.br/pc/produtos-e-servicos/para-seu-veiculo/flua-petrobras-arla-32

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Appendix

INTERVIEW SCRIPT

Job title: ____

How long have you been working in that company? ____________________________

Date of interview: ________/________/________

Start time: ____:____

End time: ____:____

Environmental performance of the company in the last three years

	2012	2013	2014
Annual production			
Electric power consumption			
Water consumption			
Volume of solid waste generated			
Environmental management expenses			
Environmental fines			

QUESTIONS:

- Why adopt ecodesign or product development practices that are "ecologically correct"? Some motivations are as follows:

Company policies and procedures;

Pressure of laws or regulations;

Consumer demand;

Marketing strategy;

Profitability;

(*continued*)

- During product development, is an analysis performed to reduce or eliminate environmentally hazardous materials? If yes, how is it done? At what stage of the process? Are there procedures or standards that guide the analysis?

- During product development, is an analysis performed to facilitate reuse of the product or part of it? If yes, how is it done? At what stage of the process? Are there procedures or standards that guide the analysis?

- During product development, is an analysis performed to facilitate recycling, the disassembly of parts and separation according to the material? If yes, how is it done? At what stage of the process? Are there procedures or standards that guide the analysis?

- During product development, is an analysis performed to facilitate the repair, rework and/or renewal of parts? If yes, how is it done? At what stage of the process? Are there procedures or standards that guide the analysis?

- During product development, is an analysis performed to optimize resource efficiency, including material reduction and energy consumption during the manufacturing process? If yes, how is it done? At what stage of the process? Are there procedures or standards that guide the analysis?

- During product development, is an analysis carried out to ensure that the product complies with environmental laws or standards (emissions, materials)? If yes, how is it done? At what stage of the process? Which procedures or standards guide the analysis?

- During product development, are recommendations followed by the strategy and/or marketing sectors? If yes, how is it done? At what stage of the process?

Corresponding author
Adriana Marotti de Mello can be contacted at: adriana.marotti@usp.br

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