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Social and Environmental Innovations in Brazilian Siderurgy

Inovações Sociais e Ambientais na Siderurgia Brasileira

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Abstract

The economic activity of the industry generates benefits, such as economic growth, and harm, such as waste discarded in the environment. The possibility of mitigating the harms of industrial activity, through sustainable innovations, is positioned as a topic of interest to society. In this context, this research analyzes the scope of socioenvironmental innovations that the Brazilian steel industry implements to mitigate the generation of solid waste. This research was based on a case study at Usiminas, one of the largest steelmakers in South America, using document analysis techniques and interviews with company representatives. The data indicate that through the performance of a multidisciplinary group the company developed four products that use the slag from the oxygen steelmaking as input. Although the product is patented, and its value is negotiated, the business model adopted was designed to contribute to the county. As a counterpart, the municipal beneficiary develops projects to protect water sources. In this way, technological innovations can transform the residue of the industry's processes into products that benefit the environment and society.

Keywords: Sustainability, Mariana's environmental accident, Environmental education, Social and environmental innovation

Resumo

A atividade econômica da indústria gera benefícios, como crescimento econômico, e malefícios, como resíduos descartados no meio ambiente. A possibilidade de mitigar os malefícios da atividade industrial, por meio de inovações sustentáveis, posiciona-se como tema de interesse para a sociedade. Neste contexto, esta pesquisa analisa o escopo das inovações socioambientais que a siderurgia brasileira implementa para mitigar a geração de resíduos sólidos. O desenvolvimento da pesquisa foi baseado em um estudo de caso na Usiminas, uma das maiores siderúrgicas da América do Sul, utilizando técnicas de análise de documentos e entrevistas com representantes da empresa. Os dados indicam que, por meio de um grupo multidisciplinar, a empresa desenvolveu quatro produtos que utilizam a escória da produção de aço com oxigênio como insumo. Embora o produto seja patenteado e seu valor seja negociado, o modelo de negócios adotado foi projetado para contribuir com o município. Como contrapartida, o beneficiário municipal desenvolve projetos para proteger as fontes de **ág**ua. Dessa forma, as inovações tecnológicas podem transformar o res**íduo** dos processos da indústria em produtos que beneficiam o meio ambiente e a sociedade.

Palavras-chave: Sustentabilidade, Acidente ambiental em Mariana, Educação ambiental, Inovação social e ambiental

1 Introduction

Nature provides all the means for human existence, making available the resources necessary for the development of society. The planet suffers the consequences of human behavior, which in turn must consider not only the use of resources, but also the measures necessary for their preservation. To produce one ton of steel, an average of 3.5 tons of other basic inputs are used (BSI, 2011).

The steelmaking process affects the environment through the consumption of natural resources and the generation of waste; this waste needs to be properly treated to mitigate its effects on the environment. This study analyzes slag, one of the residues originating in steel mills. Slag is generated in two distinctive stages: the first originates from the conventional blast furnace process that turns iron ore into pig iron; the second results from the process of transforming the pig iron into steel. The volume of slag generated in the ore transformation in the blast furnace is significant because it is proportional to the volume of material to be processed. The transformation process to create one ton of steel generates, according to van Oss (2018), 250–300 kilograms of blast furnace slag; and Araújo, Lima, & Souza (2015) reported that the transformation of pig iron into one ton of steel in the Linz Donawitz (LD) process creates 100 kilograms of slag.

The cement industry uses the blast furnace slag as raw material and is, therefore, an environmentally safe destination for this by-product; blast furnace slag can be turned from an environmental liability into a profitable coproduct. In the basic oxygen process, however, the resulting slag does not have the same possibility of application, prompting the development of studies to find an environmentally appropriate destination.

The development of innovative technologies that mitigate damages to the environment aims to establish a balance between consumption and capacity for renewal of the environment. Barbieri, Vasconcelos, Andreassi, & Vasconcelos (2010) emphasize that the relationship between sustainability and innovation is of fundamental importance for the preservation of the planet. Accordingly, there is a research need for analyses of the destination of slag that consider not only profitability, but also social, environmental and economic sustainability.

Studies that analyze the improvement of economic performance resulting from innovations hardly incorporate the environmental dimension (Lee & Min, 2015; Brasil, Abreu, Silva Filho, & Leocádio, 2016), and the inclusion of social benefits in studies of the innovation process is is less observed (Lins & Faria, 2018). The current study contributes to this research area by evaluating the economic, social and environmental benefits of innovation in a steel company.

The development of innovation projects requires technological partners with a diversified profile (Garcez, Sbragia, & Kruglianskas, 2014). Studies that portray this diversity of partnerships and cooperation (Giorgi, dal Palù, & Allione, 2015, Menezes, 2019) are interested in the possibility of market expansion (Cheng & Shiu, 2012), because environmental innovations are not limited to technological aspects: as they advance to the managerial perspective, the innovations establish an environment conducive to the generation of ideas and learning. In this context, this research analyzes the scope of socioenvironmental innovations that the Brazilian steel industry implements to mitigate the generation of solid waste.

2 Theoretical Background

New technologies need to incorporate technological advances associated with social and environmental improvements, thus enabling sustainable development. In this way, the analysis of innovations should not be restricted to the technical context; rather, they should be expanded to include analysis of social and environmental adequacy.

As a managerial representative of a company's shareholders, the board of directors has the task of evaluating the scope of benefits and risks associated with innovations, as well as monitoring performance and adequacy when new solutions are deployed. According to Tricker (2015), the board of directors is responsible for formulating the company's strategy, identifying the risks involved, determining how the company will behave, and establishing the perenniality, profitability and social responsibility of the organization's actions. An excessive use of nature resources and the improper destination of waste produced by companies exhibit; therefore, a possible deficiency in corporate governance.

In the context of the steel industry, environmental concern arises from Lavoisier's law of conservation of mass (Teich, 1982). This law of nature indicates the possibility of a path to be adopted for preservation, since productive processes belonging to a closed system, in which there is no exchange with the external environment, it can achieve sustainability by the transformation of residues in by-products to other industrial processes. Thus, it follows from the law of the conservation of mass that, in identifying the emission of pollutants or residues into the environment, countermeasures must be sought to ensure that the consumption of raw materials does not lead to to depletion; hence, the practices of recycling and reuse are recommended (Sverdrup, Ragnarsdottir, & Koca, 2017).

One of the challenges of using natural raw materials is the search for the reduction of waste discards. The importance of waste disposal is evident when one considers the increasing size of the global population. Population increase leads to an increase in the needs to be met. Table 1, published by the United Nations Organization (UN, 2017), presents a projection of the world's population by the year 2100. The data indicate that the global population will grow approximately 50% this century with stability from the year 2050 in some regions of the world. These estimates that will also be an increase in the consumption and production of goods and foods, leading to greater demand for raw materials and increased generation of residues.

Table 1. Estimation of population growth (projection of mean change)

	Population in millions			
Region	**2017**	**2030**	**2050**	**2100**
World	7,550	8,551	9,772	11,184
Africa	1,256	1,704	2,528	4,468
Asia	4,504	4,947	5,257	4,780
Europe	742	739	716	653
Latin America and the Caribbean	646	718	780	712
North America	361	395	435	499
Oceania	41	48	57	72

Source: ONU (2017).

Piatak, Parsons, & Seal (2015) reviewed 150 articles on slag and suggested that their subject matter can be classified chemically into two types: ferrous and non-ferrous. The authors point out that increasing scientific interest in the subject is reflected in a growing number of publications since 1990, and they highlight that this interest is closely related to environmental concerns: whereas limited environmental regulation and an insufficient understanding of environmental issues in the past resulted in little research, more rigorous legislation on the environmental effects of slag has prompted more research. The relationship between the volume of by-product (slag) generation and the global production of steel provides the basis for assessing the impact of slag generation on the environment.

Studies on steel slag focus on three key areas: use of slag for the manufacture of building materials; recovery of metal; environmental applications. A review of Piatak et al. (2015) indicates the predominance of paper about slag from iron ore processing, since this has a higher production. The focus of this research is on the generation of steel slag, that is, slag generated by the LD, or oxygen converter, process, which is predominant in steel production. The most common applications for the disposal of steel slag originating from the Brazilian steelmaking process are in the paving of highways, railroad ballast, containment of slopes and embankments (Araújo et al., 2015). However, the use of this material in other applications such as brick making, ceramics, cement mixing and fertilizers.

In order to meet sustainability demands, solutions must incorporate social, environmental and economic aspects, and these establish the basis for the development of social and environmental innovations. Barbieri et al. (2010) and Aloise and Silva (2018) point out that the innovation process of organizations must incorporate the mitigation of social and environmental problems. Thus, sustainable innovation benefits the economy, society and the environment, contributing to the concept of sustainable development. According to Mulgan (2006), social innovation arises from a decision to innovate that is focused on meeting human needs. Maurer and Silva (2014) indicate that social innovation is intended to solve social problems that affect humanity.

Holmes and Smart (2009) and Sausen, Rossetto and Behling (2018) take a social entrepreneurship approach to social innovation. In this approach, the importance of companies expanding their borders emerges, thereby strengthening the process of innovation and its social legitimization. For Bridgstock, Lettice, Özbilgin and Tatli (2010), social innovation emphasizes the importance of ideas and the understanding that the social condition can be improved. Thus, social innovation satisfies unmet human and social needs, differentiating itself from business innovation that focuses on the consumer and the market.

Environmental concerns are also presented in the context of sustainability, so technological processes and products must incorporate innovations that meet these demands. According to Kemp and Pearson (2007), environmental innovation looks at the entire life cycle of a new product, including its production process, service, or business model. In this way, the company seeks to adjust the product and its life cycle, in order to they mitigate environmental risk, pollution and other possible negative impacts arising from the use of resources.

Environmentally and socially responsible innovations lead to technological, institutional and organizational changes that alter the knowledge base of production systems (Lopez, & Montalvo, 2012). Additionally, van den Bergh, Truffer and Kallis (2011) emphasize that, in industry, the transition to sustainability relies on new forms of environmental innovation. Machado Junior, Souza, Bazanini, Mantovani and Furlaneto (2018) emphasize that in Brazil social innovations seek to meet the needs of neighboring communities, while environmental innovations are aimed at improving processes and products, as well as reducing the consumption of resources involved.

The steel industry is receptive to changes that mitigate the impact of its activities on the environment, and society. Shen et al. (2019) present the negative impact of the Chinese iron and steel sector on the environment, evidenced by the growing environmental burden of the sector. The growing negative impact of the Chinese iron and steel sector on the environment opposes the process of establishing stricter environmental legislation in China (Zhu, Zeng, Zhong, Huang, & Qu, 2019). The balance between the environmental impact caused by the Chinese iron and steel sector and the Chinese environmental regulation can only be achieved through the implementation of technology innovation that incorporates environmental aspects (Yuan & Zhang, 2020).

The concern to reduce the environmental impact of the iron and steel sector, through innovations, is also present in other countries, as indicated by the research by Kushnir, Hansen, Vogl and Åhman (2020), which presents the effort of the Swedish steel industry in CO_2 emission mitigation, using direct hydrogen reduction instead of continuing with coke-based blast furnaces. The study by Arens (2019) highlights that in Europe the iron and steel sector is part of an effort to reduce waste, and emission of carbon dioxide, supported by technological advances. Therefore, that the development of innovations that mitigate the environmental impact of the iron and steel sector is a worldwide concern, and that Brazilian initiatives that combine with this context are necessary.

Highly polluting industries face pressure from society to exploit technological innovation in the environmental improvement of their production processes (Wang, Zhao, Chen, Wu, Tsai, & Wang, 2019). It identifies the existence of a relation between corporate social responsibility (CSR) and performance in innovations that incorporate the mitigation of environmental impact in polluting industries such as steel industry (Wang et al., 2019). Steel industry is more likely to adopt information strategies that report CSR activities, because of its position in a controversial sector with regard to the environmental issue (Vollero, Conte, Siano, & Covucci, 2019).

3 Method

This research is classified as exploratory, using data in a qualitative approach. Most innovation processes are treated confidentially because they include strategic aspects of the company. It was carried out at Usinas Siderúrgicas de Minas Gerais S.A. (Usiminas), an important steelmaking company in Brazil that produces and commercializes low-carbon flat steels such as hot-rolled, cold-rolled and coated laminates. The Usiminas group has its main productive activities in the city of Ipatinga, in the state of Minas Gerais, Brazil. This context justifies the relevance of the company as the subject of this research, since its actions and innovations have the potential to influence the steel industry sector.

The search for data was carried out through field research, supported by two research techniques were used: documentary research and interview. The first stage of the research was the document analysis using reports, which were made available by the company in two ways. The first was information available on its website, which is freely accessible to all. The Usiminas website presents a wide range of documents and information available. Through this consultation, the researchers accessed three corporate social responsibility reports containing details of the object under study. The second source of information comprised documents prepared by the company for restricted disclosure, but to which a stakeholder can grant access at request. Through this protocol, the researchers accessed three meeting reports of the board of directors and two strategic planning reports.

After analyzing the documents, the researchers conducted a semi-structured interview with the corporate manager of coproducts and sustainability at Usiminas. This professional was chosen for the interview because he is responsible for the development of the project, Caminhos do Vale, which is being analyzed in this research. He has a degree in administration and has held this role since January 2015, although he joined the company in January 1999. The interview script used raised questions of interest to meet the proposed objective, based on the theoretical framework developed and the documentation analyzed in the first phase of data collection.

The research focused on the Caminhos do Vale project by approaching the so-called “slags” that are of interest in this study. The limitations of this study are those intrinsic to research based on a single case study, the need to establish caveats regarding the application of the results obtained to other institutions. An additional limitation of this research is that some data are protected by the patent that the company has on the researched compound. This factor limited the detail that could be presented about the process and product used by Usiminas, but it did not compromise the analysis of the investigated phenomenon.

4 Results and Discussion

In 2014, Usiminas, in the middle of the economic crisis, faced difficulties in the management of environmental liabilities when it discovered an environmental liability related to blast furnace slag. The volume of accumulated blast furnace slag reached the limit of the capacity of the storage yard, thus establishing the need for the company to find an appropriate and definitive destination for this by-product. After a topographical survey, it was estimated that the stock of steel slag amounted to between 2.5 million and 3.0 million tons, with the aggravating fact that the material approached the bank of the Piracicaba river, a tributary of the Rio Doce in Minas Gerais.

This proximity represented the risk part of the material would migrate to the riverbed, contaminating its ebb. Solid waste created environmental concern for the company and the surrounding community. Although steel slag is a solid waste and classified as inert, which reduces environmental risk, it received the same attention and concern of the company. According to Law 18.031 (2009), which provides for the state’s solid waste policy, the technical classification of the steel slag was “solid inert waste, Class II-B”.

The problem concerned the amount of waste accumulated over time, which was compounded by the monthly generation resulting from the steelmaking process. The Usiminas production process generates around 60,000 tons of steel slag per month. State law limits storage of this material to six times the monthly generation; in this case, the limit is 360,000 tons. The data indicate that, in 2014, the company had a total volume of waste seven times more than allowed by law (7 x 360,000 tons). The steel slag is accumulated in an intermediary patio to receive treatment, and then transferred to the storage yard. The blast furnace slag is, in most cases, used in the cement industry, whereas the slag from the basic oxygen furnace had no proper destination.

As a result of this high volume of steel slag stored by the company, the state environmental agencies and the Public Ministry questioned the institution about the irregularities. A serie of meetings took place between the parties involved; they defined deadlines for the normalization of this environmental liability. At this time, the simplest destination for the slag was to make landfill, avoiding its dispersion to the environment; however, there were no studies to evaluate its dispersion in the subsoil, and this solution does not eliminate the environmental liability, resulting from the accumulation of material in the subsoil. Slag landfills are an expensive solution as they cost 40 USD per ton.

In view of the costs involved and the failure to identify a definitive solution for the solid waste from hot rolling, the presidency and the board of directors of Usiminas tasked the management involved to find a definitive solution for the steel slag that took into consideration economic, environmental and social factors. The management team was encouraged to find an innovative and sustainable solution that, following Barbieri et al. (2010), seeks economic, social and environmental benefits, in line with the sustainable development. The involvement of the board of directors in this process resulted from analysis of the risks, since the agreement with the environmental agencies and the state's public ministry established the possibility of fines and/or suspension of activity. This context is in line with Tricker's (2015) argument that the board of directors should not only weigh the risks, including the environmental risks, but should also formulate strategies to mitigate these risks.

Because of the complexity and involvement of several areas of the company, a matrix group, consisting of representatives of all the departments involved, was formed. This matrix group, named the Working Group Coproducts (WG Coproducts), had representatives in six areas: environment; social development; special sales; industrial engineering; research center; coproducts. It is noteworthy that Usiminas is the only steel mill in Latin America that has a research center dedicated to the development of steel and its coproducts, and this facilitated the development of WG Coproducts.

Initially, the working group investigated existing knowledge about the destination of steel slag and its applications, and it identified that the correct destination of this waste is a worldwide concern, as well as some possible destinations for the material. The initial point of the research at Usiminas was based on aspects related to the risks involved. As indicated by Araújo et al. (2015), the slag from hot rolling is an inert and non-polluting material. Given this, the first application was the use of the material as a substitute for gravel in paving roads, since gravel involves the extraction of a natural resource.

This initial action resulted in a certificate issued by the National Department of Transport Infrastructure (DNIT); the application of the steel aggregate produced by Usiminas was a more economical alternative to the natural aggregate (gravel). According to the DNIT (2017), Usiminas was a relevant participant in the initiatives that led to the approval of the Açobrita® project, a partnership between DNIT and the Brazilian Steel Institute, which involved ArcelorMittal, Gerdau and the University of Brasilia.

This process resulted in the formulation of the Brazilian standard ABNT NBR 16364 – Execution of granulometrically stabilized sub-base and base with steel aggregate for road paving – procedure (may 2015), and two technical specifications, DNIT 406/2017 – stabilized base granulometrically with Açobrita® – service specification, and DNIT 407/2017 – ES – sub-base stabilized granulometrically with Açobrita®. From the project developed with the DNIT, Usiminas registered four patents for products derived from steel slag. The company registered the trademark in the National Institute of Industrial Property for the product Siderbrita®, with four patents: Siderbrita_Registro 908569980; Siderbrita_Registro 908570120; Siderbrita PLUS_Registro 908570317; and Siderbrita PLUS_Registro 908570392.

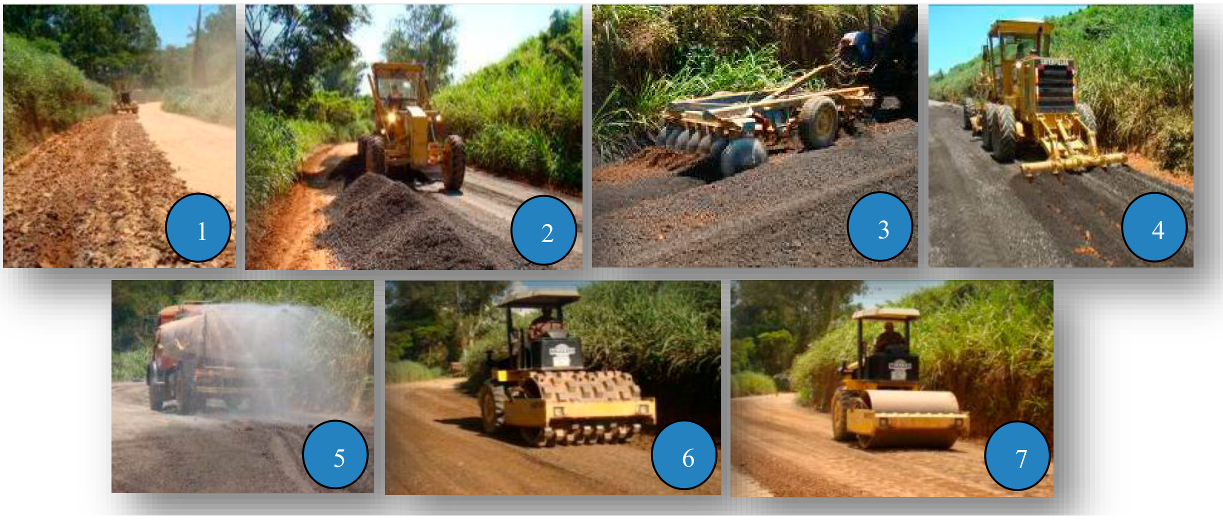
Consequently, the outcome of WG Coproducts of Usiminas was the publication of a Brazilian technical standard, the establishment of two technical specifications issued by the DNIT, and the registration of four patents by Usiminas. These elements are related to the use of hot basic oxygen slag in the paving of roads. The process changes in which a material is used for another purpose, such as that performed by Usiminas, aligns with the environmental innovation, proposed by Kemp and Pearson (2007), for taking care of the entire product life cycle, including waste generated in the manufacturing process.

The development of the new product derived from hot rolling slag, a substitute for crushed stone, and the demonstration of economic and environmental feasibility, enabled Usiminas to implement the social aspects associated with of the product through the Socioenvironmental Coparticipation Program. The program consists of the donation of free steel slag for the paving of rural roads in surrounding municipalities.

Usiminas adopted this action because several municipalities in Brazil have precarious infrastructures and unpaved local roads, which limit the accessibility of communities and consequently their development. Roads with poor surface conditions negatively influence several sectors of the municipality, such as education, family farming, rural tourism, garbage collection and contact with large cities. This situation arises because of the low budget available for paving of local roads that integrate these towns and small cities and connect them with their closest and developed centers.

The soil application of the developed product has a different methodology, which needs to be passed onto the municipalities involved. The application of the material on a rural road involves mixing the aggregate with soil to form a compound. This blend has an ideal ratio in order to achieve the desired quality and durability of the coating. This mixture is the responsibility of the municipality, but Usiminas supervises the process. It is also the responsibility of the municipality to determine the places where the mixture will be made, as well as its storage before use. Usiminas developed the process to be carried out by the city hall, before the application of the compound. This process is subdivided into seven stages: preparation; spreading the material; homogenization; initial mixing; humectation; landfill compaction; final compaction. These stage are presented in Figure 1.

Figure 1. Application of the aggregate compound on a rural road



Source: Usiminas (2018)

Note: Image 1 – preparation; image 2 – spreading the material; image 3 – homogenization; image 4 – initial mixing; image 5 – humectation; image 6 – landfill compaction; image 7 – final compaction.

This process is carried out with the purpose of adjusting the soil to the application of the compound. The routine use of the road also increases the compaction of the compound and consequently improves the traffic conditions for vehicles. In addition, soil compaction generates the benefit of no dust suspension, increasing the safety of its use. Another observed benefit is that soil compaction establishes better conditions of use in the rainy season, avoiding the need for a large ditch, which would limit the circulation of vehicles.

The practice of coating rural roads with slag is not new; however, the use of the material with no incorporating the treatment and application process developed by Usiminas was inefficient, restricting its use by municipalities. The advantage derived from the use of the slag treated by Usiminas is evidenced by the better soil compaction that facilitates the movement of heavy vehicles, ensuring that they can use the road even on rainy days.

The availability of the material free of charge by Usiminas to the municipalities involves socioenvironmental counterparts established between the parties through contracts, which aimed at improving the social condition of communities around small towns. The action constitutes a social innovation, as outlined by Mulgan (2006), because the measure is proposed as an innovative solution designed to meet human needs. In addition, the measure is based on the understanding that the social condition may be improved, as outlined by Bridgstock et al. (2010).

The counterparts requested by Usiminas are characterized by the commitment of the municipality to preserve and recover its water sources. This recovery project was created in 2015 in partnership with the Minais Gerais Public Ministry and the Instituto Interagir (2018). The project, known as Mapa da Mina, is intended for the recovery of water sources in the municipality of Ipatinga. This initiative consisted of the identification, mapping and cataloging of all water sources in the city of Ipatinga, and it encouraged the recovery of springs that have been degraded in rural and urban areas.

A preliminary survey identified 300 springs within the municipality, of which approximately one third were degraded. The development of the project made it possible to identify a new set of springs, previously not cataloged, currently totaling 565 springs in Ipatinga. The springs were cleaned and, for their recovery and preservation, the practice of planting trees around the source was adopted. The trees used in this planting originate from a nursery that Usiminas maintains in another environmental initiative, called the Xerimbabo project (Usiminas, 2017).

The development of the Mapa da Mina project had the assistance of the defense and environment prosecutor of Minas Gerais, which were incorporated within multidisciplinary teams trained to cover the properties and catalog the springs. A wide range of equipment and practices were used, such as a global positioning system locator, photographs, environmental reports, and contact with rural owners. A highlight of this program is that the water from Ipatinga springs flows into the Piracicaba river, and in turn to the Rio Doce, meaning that all preserved water will help in the recovery of the Rio Doce from its contamination by the 2015 collapse of the Fundão dam, owned by the Samarco company, in the city of Mariana.

The Mapa da Mina project includes an environmental education initiative with the students of the municipal educational system of Ipatinga. This project is in addition to that developed by the Fundação Renova, whose task is to recover the course of the Rio Doce affected by the collapse of the Fundão dam in Mariana. It was one of the worst environmental accidents in Brazil and led to the degradation of the Rio Doce, which supplies to several cities in the states of Minas Gerais and Espírito Santo. The Mapa da Mina project to recover the springs directly contributes to the Fundação Renova project to mitigate the effects of the collapse of the Fundão dam:

> About 250 rural properties will receive aid for the protection of 533 springs, of which 375 are in Minas Gerais and 158 are in Espírito Santo, in the second year of action on the Springs Recovery Program and other APPs of the Renova Foundation. The selection of protection zones was carried out by the Basin Committees (CBH) Suaçuí, Pontões and Lagoas do Doce and Piranga, which defined the cities of Coimbra, São Vítor (district of Governador Valadares), Galileia and Periquito in Minas Gerais and Marilândia, Pancas and Colatina, in Espírito Santo, as the focus for this year. Together with community leaders and public authorities, the CBHs continued to participate in the mobilization of farmers in these areas (Fundação Renova, 2017).

The Usiminas initiative in requesting the recovery of the water springs by the municipalities as a counterpart to the company's donation of the compound used in the rural roads incorporates aspects of environmental and social innovation. The environmental aspect is the maintenance and recovery of water springs, thereby providing environmental balance to the municipality and the region.

This action is in line with the perspective of Lopez and Montalvo (2010), according to which environmental and social innovations provide institutional and organizational changes that alter the knowledge base of the systems, which are the residents of the municipality and the regions affected by the environmental accident of Mariana. In addition, the project developed by Usiminas can be regarded as a social innovation, in line with Maurer and Silva (2014). It also aligns with the approach of Bridgstock et al. (2010), according to which companies should collaborate to change the social condition and provide improvements for people.

In the social context, the inclusion of the students from the municipal education network in the process of preservation of water sources aims at environmental education as an instrument of cultural transformation for the new generations. This activity can be regarded as social entrepreneurship, in line with the work of Holmes and Smart (2009). The city of Ipatinga piloted the initiatives developed by Usiminas; the process was extended to four cities in the area: Santana do Paraíso, Coronel Fabriciano, Timóteo and Marliéria. In 2017, the Usiminas project served 26 cities in the steel valley, including the city of Governador Valadares, all in the state of Minas Gerais. For 2018, Usiminas plans to provide the material and technology to other municipalities, with the goal of serving 36 municipalities. Table 2 presents the main results of the project achieved by the end of 2017.

Table 2. Main results of the Caminhos do Vale project

Main results of the Caminhos do Vale project until the end of 2017
1,181 km of recovered roads
36 municipalities benefited
1.5 million tons applied to paving projects
35 recovered bridges
1,248 recovered water springs
1,03 million of people as beneficiaries
80 km of urban roads recovered

Source: Usiminas (2018).

The program of concession of material and technology for the paving of rural roads is open to the participation of every municipality. Any municipality that wishes to participate in the program must register with Usiminas, whose environmental department will then carry out analysis to identify areas of temporary storage for the deposit of the steel aggregate and sites for the preparation of the compound. The inclusion of municipalities in the program is limited to Usiminas' own capacity to generate basic oxygen slag.

Usiminas has developed a practical application for one of the residues of its ore transformation process; previously, this residue was discarded as solid residue. The new destination for the material by Usiminas is in line with the approach outlined by Sverdrup et al. (2017), according to which companies must establish recycling and reuse practices in order to mitigate the environmental impacts resulting from their activities. The innovation process developed by Usiminas incorporates the mitigation of social and environmental problems, as proposed by Barbieri et al. (2010). In this case, in addition to the environmental benefit, there is a social return, both through the donation of material for municipalities to improve their rural roads, and through the development of projects to preserve water springs.

5 Final Considerations

The research developed at Usiminas, which operates in the steel industry, indicates that, when companies need to find solutions to the operational challenges, they are able to adopt alternatives that address social and environmental concern in addition to economic considerations. The existing alternative of burying the slag from the steelworks involved t operating costs, as well as uncertainty about possible environmental impact. The multidisciplinary working group around a project, which was tasked with identifying an appropriate destination for the slag, reported directly to the top management, and to the board of directors, denotes the importance that Usiminas attributed to this project.

The search for the adequate destination of basic oxygen slag residue involved forming a multidisciplinary group with members from various departments of the company, and it included the development of new products. This makes clear the company's search for an innovative solution. The process made possible the development of new applications, including the patenting of four new products, the issuance of a Brazilian standard, and two technical instructions issued by the DNIT, outcomes that benefit society as a whole.

The use of the new product from the basic oxygen slag followed a different business model. Although the product is patented, and has a value that can be negotiated and that would increase the company's profits, the business model adopted was to donate the product to the city halls, which included the provision of training for the municipal officials who used the product at the construction sites. This approach highlights the social benefit of the proposal adopted by the company, which adds to the benefits resulting from the improvement of the rural roads and the social infrastructure of their areas. The benefits for these societies are that the new paving of the roads avoids their deterioration, making possible the flow of cars and roads in the rainy season, and enabling the greater ease for the transportation of rural produce.

The company's decision to request as a counterpart that the municipalities develop projects to protect water springs can be considered as an important environmental innovation. The counterpart that the city halls must accomplish benefits the environment and the population, since it generates a greater volume of potable water that can be used for consumption, and irrigation of plantations. Therefore, the Usiminas initiative has both environmental and social benefits. In addition, the use of the hot rolling slag for the paving of the roads replaces the traditional crushed stone, which is obtained by means of detonation and subsequent fragmentation of crude stones. Reducing the consumption of crushed stone brings environmental benefits, as it reduces the consumption of natural materials.

The cities in which the project to identify and maintain the water springs was implemented indicate the additional benefit of providing a greater volume of clean water to the rivers that flow into the Rio Doce. The collapse of the Fundão Dam in the city of Mariana caused the complete destruction of Bento Rodrigues locality, the contamination of the Rio Doce with mining debris, and the extinction of endemic species. Thus, projects that allow a greater volume of clean water for the Rio Doce are considered as important, since they act to mitigate the largest environmental accident involving a mine tailings dam.

According to the data obtained, the alternatives that the Brazilian steel industry adopts for the destination of the slag from the steelmaking process are adequate from the perspective of sustainability, since they incorporate economic, social and environmental aspects, and are based on processes of innovation of products and processes.

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