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SUSTAINABILITY IN MINING: AN APPLICATION OF PROMÉTHÉE II

Abstract

This article deals with the use of a Multicriteria Decision Aiding method in the evaluation of environmental sustainability. Environmental indicators related to sustainable development require interconnected systems to provide a progress evaluation within a development context for a country, a region, a community or an industrial sector of the economy. The focus of this article is the evaluation process that involves the main players in the mining and metallurgy industries, based on the principles of the Global Report Initiative (GRI). The use of multicriteria analysis aims to offer stakeholders, in particular risk agencies and investment funds, a structured approach to the environmental performance of the mining sector. In this article it is shown how that approach can be put into practice by using the PROMÉTHÉE II method of Multi-Criteria Decision Aiding, providing a more global and transparent result. The selection of some specific indicators led to capturing potential problems in a clear and concise way. The multi-criteria evaluation study presented in this article can be complemented in the future by considering the other environmental indicators of the GRI, even those of a qualitative nature as described by specific actions of environmental management.

Keywords

Mining industry, sustainability, outranking methods, environmental management.

Introduction

This paper deals with the application of a Multicriteria Decision Aiding method in the evaluation of environmental sustainability. The evaluation involves the main players in the mining and metallurgy industries, based on the principles of the Global Report Initiative (GRI). The use of the multicriteria analysis aims to offer stakeholders, in particular risk agencies and investment funds, a structured approach to the environmental performance of the mining sector. This is accomplished by providing an evaluation of the risks associated with environmental sustainability in the sector, and, in this way, orientate investors on the application of funds in organizations whose environmental risks are to be found within the accepted boundaries defined by these entities. In order to do this, specific environmental indicators are considered and, in this fashion, greater transparency is provided to environmental management in this economic sector [Villas Boas and Beinhoff (eds.), 2002]. The decision analysis carried out through this approach is indeed a decision aiding tool within the decision making process, as it permits a relatively large problem to be broken down into a set of situations of less complexity.

The concept of sustainable development has arisen from a relatively long historical process of critical re-evaluation of the relationship of society and its natural environment. As it deals with a continuous and complex problem, even today a variety of approaches can be observed which seek to explain the concept of sustainability. The term sustainable development was first discussed by the World Conservation Union, according to which, for development to be sustainable, it must consider aspects related to social and ecological dimensions, as well as economic factors, living and non-living resources and the short and long term advantages of alternative actions. The focus of the concept is environmental integrity and, only from the definition of the Brundtland Report does the emphasis shift to the human element, creating a balance between the economic, environmental and social dimensions [WWF-Brazil, 2009]. The GRI, in turn, is a broad network of multiple stakeholders composed of thousands of specialists in dozens of countries around the world. The guidelines of the GRI are a set of indicators and recommendations which define a global standard of distribution of information on economic, environmental and social performance [GRI, 2009]. Environmental indicators related to sustainable development require interconnected systems to provide a progress evaluation within a development context for a country, a region, a community or an industrial sector of the economy.

For the process of evaluation and decision making, particularly in the presence of multiple criteria – which are often conflicting – the main role of the analysis is to make clear to those involved in the process the understanding of the problem in question, including here all the variables and actors involved [Belton and Stewart, 2002]. Recent references on multi-criteria sustainability evaluation in mining are scarce in the literature [Esteves, 2008; Slowinski, Greco and Matarazzo, 2002].

Each evaluation or decision criterion, in particular, is a tool which permits the comparison of alternatives according to a particular point of view. The success of the decision aiding process is strongly dependent on the way in which the family of criteria is created. In this way, under the multicriteria focus, there is a need to construct several criteria representing different points of view, allowing the evaluators to express their preferences, which should be seen as partial, as they are restricted to the aspects which each particular criterion covers [Bouyssou, 1990].

The major financial institutions, either national or international, as well as risk credit agencies have professionals dedicated to socio-environmental risk analyses of companies. Those analyses provide bases for credit concession processes as well as investment information to the stock market [City Group, 2011; Goldman Sachs, 2011; Standard & Poors, 2011]. Setting an investment strategy in the stock market relies on an evaluation on socio-environmental grounds. This evaluation aims to keep investment risks within a tolerable margin and at the same time to provide adequate long run returns. Evaluating the way mining companies manage environmental issues by coping with legal requirements and corporate obligations is a fundamental procedure for checking how such companies differ in their governance models and responses to risk exposures.

At present risk agencies such as Goldman Sachs, Citigroup and Standard & Poors perform evaluations of the environmental sustainability of large companies (i.e. companies with market values above 3 billion dollars). This is normally accomplished by taking into account environmental requirements in an isolated fashion. In other words, criteria such as: emission of greenhouse effect gases, consumption of new water, area affected by mining, generation of wastes, etc. are not considered jointly within a broad framework. A visit to the sites of the main risk agencies and financial institutions can verify that reports on environmental sustainability are based on analyzing each indicator separately, without relying on a holistic approach. Through this paper we show how that approach can be put into practice by using the PROMÉTHÉE II method of Multicriteria Decision Aiding, providing a more global and transparent result.

1. Problem definition

1.1. The GRI

The GRI is a broad multi-stakeholder network composed of specialists in dozens of countries around the world. They participate in the GRI work-groups and governance bodies, use its guidelines in their reports, access information in reports based on it and contribute to the development of its structure of reports in other ways, both formally and informally [Gallopin, 1996]. The GRI guidelines are a set of indicators and recommendations which define a global standard of disclosure of information on economic, environmental and social performance [GRI, 2009].

1.2. Environmental performance

The environmental dimension of sustainability relates to the impact of the organization on natural living and non-living systems, including biotic and physical environments (soil, air, water). The environmental indicators cover the performance related to raw materials (such as materials, energy, water) and generation (air emissions, wastes water, solid wastes). In addition to this, they consider performance in relation to biodiversity, to environmental legal conformity and other important information such as environment expenses and the impacts of products and services.

1.3. Management

The report must supply a concise description of the environmental management approach, with references to the following environmental aspects: materials, water, biodiversity, air emissions, wastewater and solid wastes, products and services, legal conformity, transport, and general aspects [GRI, 2009].

1.4. Indicators of environmental performance

The aspects contained in the environmental indicators are structured so as to reflect the raw materials, outputs and types of impact that the organization generates in the environment. Energy, water and materials represent three basic types of raw materials used by the majority of the organizations. These raw materials result in relevant outputs from the environmental point of view and are described in the environmental aspects related to air emissions, wastewater and solid wastes. Biodiversity is also related to the concept of raw materials, in the sense that it can be considered a natural resource. However, biodiversity also suffers the direct impact of outputs such as pollutants.

Aspects related to transport, products and services represent areas in which an organization can also have a negative impact on the environment. Generally, this occurs through third parties, such as clients or logistic service providers. Legal conformity and general aspects, in turn, are specific actions that the organizations, according to the GRI, adopt in the management of their environmental performance, such as, for example: ensuring that the industrial wastewater is correctly treated before being released into water courses or implementing and maintaining water sprinklers through internal mineshafts in order to avoid the emission of particulate material.

1.5. Energy

The energy indicators cover the five most important areas of energy consumption by organizations and include both direct and indirect energy. The consumption of direct energy is the amount consumed by the organization to obtain products and to provide services. The consumption of indirect energy, in turn, is all that consumed by others which serve the organization.

The five different areas of energy consumption to which the indicators are associated are described as follows:

– The EN3 indicator relates to the consumption of direct energy by the organization, produced on site.
– The EN4 indicator supplies information related to the consumption of energy necessary for the production of energy purchased externally.
– The EN5 indicator supplies information on energy economized due to improvements in conservation and efficiency.
– The EN6 indicator covers the development of products and services with low energy consumption.
– The EN7 indicator covers the consumption of indirect energy by the activities of the organization.

1.6. Emissions

The aspect related to air emissions, wastewater and solid wastes deals with indicators which measure standard emissions in the environment and which are considered pollutants. These indicators include various types of pollutants which are typically considered in regulatory structures (EN20 to EN23 and EN24). In addition to this, there are indicators for two types of emissions which are the subject of international conventions: greenhouse effect gases (EN16 and EN17) and substances which destroy the ozone layer (EN19). Indicator EN18 covers, in a qualitative way, reductions in emissions achieved and initiatives to reduce these emissions.

2. Case study

2.1. Choice of analytical method

The difficulty in decision making when classifying companies with respect to their environmental performances, by means of the GRI indicators, naturally imposes the use of multicriteria analysis, in the sense that different subjective attributes and aspects are considered, such as: initiatives to supply products and services with low energy consumption, a description of the significant impact of the activities on biodiversity, products and services in protected areas, strategies, measures in operation and future plans for the management of impact on biodiversity, among others. The choice of the multicriteria method to be used, however, depends on the type of problem under analysis, the context studied, the actors involved, the structure and preferences and the type of response which is sought; in other words, the reference problem [Figueira, Greco and Ehrgott, 2005]. The problem approached in this case study, in particular, has as its objective a classification and ranking of alternatives, considering the principal players in the global mining industry, subject to the influence of various environmental performance indicators, according to the GRI standard. The group selected is composed of companies which have an estimated market value of more than USD 10 billion and which published their sustainability reports in 2006. In this way, the selected companies were: BHP Billiton, Vale, Anglo American, Rio Tinto and Xstrata, all open companies with stocks negotiated on the stock exchanges of the United States or the United Kingdom. Each of the environmental indicators will be considered as an evaluation criterion and, therefore, will require inter-criteria information which corresponds to its relative importance in the context of environmental sustainability. For these cases, a special use of the French School methods is recommended, using an approach based on the aforementioned concept of the relation of outranking [Roy and Bouyssou, 1993].

From among the methods based on relations of outranking developed to select, rank and classify the environmental performance indicators of the main players in the mining industry, considering the premises of the GRI, the PROMÉTHÉE family of multicriteria methods was selected as the problem requires a ranking of the alternatives (companies) taking into account the indicators of environmental sustainability. Within that family the PROMÉTHÉE II method was chosen due to its advantage of requiring very clear additional information, which can easily be obtained and managed both by the decision agent and the analyst. This additional information is introduced through the aforementioned generalized criterion, to capture the range of the differences among the evaluations of each of the criteria, enriching the preference structure. Furthermore, PROMÉTHÉE II is a flexible multicriteria method, offering two degrees of freedom to the decision agent: the first relates to the selection of the type of preference function and the second one, to the selection of defining thresholds [Brans and Mareschal, 2002].

It can be observed that the choice of PROMÉTHÉE II is based on the fact that the method, like other methods of the French School, requires intense interaction between the decision agent and the analyst to ensure that the parameters used are clearly defined. In addition to this, the parameters of the model must represent the unanimous consensus of the group or at least the position of a significant majority [Leyva-López and Fernández-González, 2003]. The PROMÉTHÉE II method provides a definition of degrees of preference represented by a real number, which varies from 0 (indifference) to 1 (strong preference). In the case study, this means: a) a comparison of the environmental performance indicators of the main global mining companies, considering the advantages of one over another, without neglecting the common characteristics among them, b) that the criteria for the definition of the environmental performance indicators and the alternatives for each of them are not clearly defined and c) that the criteria and the alternatives are connected, in such a way that one determined indicator can partially reflect another one.

PROMÈTHÈE II was the chosen multicriteria method, although a number of other methods could be used. The highlights of the method were explained to the experts and they felt comfortable with the kind of information they were supposed to provide for its use. They also seemed to understand the notion of generalized criteria, a notion that would serve for capturing the strength of differences between evaluations according to various criteria. This last aspect of PROMÈTHÈE II is regarded as a way to enrich the structure of preference. Coupled with its relative understandability and used by participants in the evaluation process it led to the decision to use PROMÉTHÉE II for tackling the problem. Another important aspect that favored the choice of PROMÈTHÈE II was the intense interaction required among participants and analyst to search for a group consensus on the values of the parameters of that method [Leyva-Lopez and Fernandez-Gonzalez, 2003]. The participants were experts with an average of 20 years of professional experience in different aspects of the mining industry. None of them had a previous experience with the use of methods of Multicriteria Decision Aiding. A number of meetings with these professionals took place to obtain the evaluations needed by the analytical method.

2.2. Computations by PROMÉTHÉE II

This phase included the processing of the data from the sustainability reports of the mining companies using the Decision Lab software [Visual Decision, 2009], with the aim of obtaining the results of the calculations according to the PROMÉTHÉE II method. In this phase a sensitivity analysis was then carried out in relation to the weights used. For the purposes of the research, the environmental performance indicators chosen were those most representative from the environmental sustainability point of view, in relation to the mining industry. The indicators selected are presented in Table 1.

Table 1

Indicators of environmental performance chosen

Type of management	Indicator	Description
Materials	EN1	Materials used by weight and volume
Energy	EN3	Consumption of direct energy discriminated by primary source of energy
	EN4	Consumption of indirect energy discriminated by primary source
Water	EN8	Total water removed by source
	EN10	% and total volume of water recycled or reused
Biodiversity	EN11	Location and size of area owned, leased or administered within protected areas, or next to them, and areas with a high level of biodiversity outside the protected areas
	EN13	Habitats protected or restored
Emissions, effluents and residues	EN16	Total direct and indirect emissions of greenhouse effect causing gases
	EN20	NOx, SOx and other significant emissions by type and weight
	EN21	Total water disposal, by quantity and destination
	EN22	Total weights of residues, by type and method of disposition
Conformity	EN28	Monetary values of significant and total number of non--monetary sanctions resulting from non-conformity to environmental laws and regulations

Table 2 presents the data of the companies researched, obtained from the 2006 sustainability report with the respective weights. The environmental indicators associated with water consumption (EN8), recirculation of water (EN10) and the size of the areas impacted (EN11) received the greatest weights on the grounds that they are the most significant in environmental terms for the mining industry.

Table 2

Values and weights of the selected environmental performance indicators

Indicator	Anglo Gold	BHP	Vale	Rio Tinto	Xstrata	Weight
EN1 – t	12061000	4186100	0	0	0	2.5
EN3 – peta joules	300	304	0	258	25.5	5.0
EN4 – peta joules	0	0	0	0	37.7	5.0

Table 2 contd.

Indicator	Anglo Gold	BHP	Vale	Rio Tinto	Xstrata	Weight
EN8 – m^3	582000	204250000	140000000	391000	85600000	20.0
EN10 – m^3	0	170000000	114800000	0	101300000	20.0
EN11 – ha	8000	0	0	350	8829	15.0
EN13 – ha	0	2400	400	401	992	15.0
EN16 – t	36447000	51000000	0	28300000	0	5.0
EN20 – t	136000	259850	0	0	252888	2.5
EN21 – m^3	208328000	88180000	0	0	7258000	2.5
EN22 – t	278913	202530	0	2192000	957600000	2.5
EN28 – USD	0	141526	0	56800	8100	5.0

Environmental problems caused by mining activities are of different types. One of them concerns disturbing the land surface through mining and it is foremost present in open-pit mines. Mining activities can also contribute to polluting surface and groundwater by mining materials, concentration of chemical products used in the processing stage, lixiviation and flow of sediments to hydric bodies. Based on those major environmental impacts, higher values for weights were therefore assigned taking into consideration impacts associated with water impounding, generation of wastes, biodiversity and emission of greenhouse gases. Lower weights were assigned to other impacts. This rationale is not only aligned with the environmental perspective in terms of impacts, but it also meets the 2000 Millenium Goals concerning loss of biodiversity, access to potable water and rehabilitation of degraded areas [United Nations, 2000].

The value 0 shown in Table 2 is used to represent information not available in sustainability reports analyzed. As a matter of fact, the GRI allows different levels of reporting and in 2006 not all companies surveyed disclosed or had information on all environmental sustainability indicators. The weight values ranging from 2.5 to 20, also shown in Table 2, were defined through meetings with the experts. Those were then asked to associate the degree of importance of criteria by weights. Therefore, weights in Table 2 add to 100. Using sensitivity analyses, the analyst deals with cases where information was incomplete.

2.3. Results

2.3.1. Outputs from Decision Lab

Using the command *View*, option *Rankings*, the total classification shown in Figure 1 is obtained.

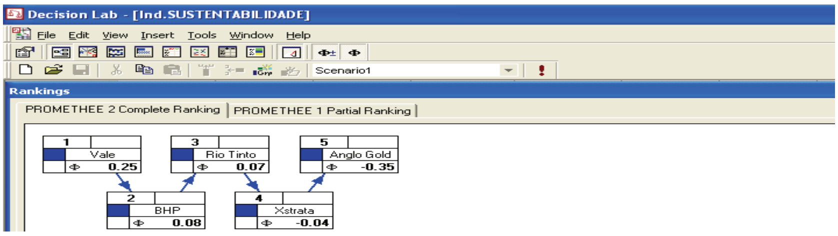

Figure 1. Classification of the companies

2.3.2. Sensitivity analysis of PROMÉTHÉE II

The sensitivity analysis of the results of PROMÉTHÉE II was carried out with respect to the variation of weights, with the purpose of evaluating alterations in the results due to fluctuations in their values. With respect to the criteria weights, five additional options to the scenario were chosen in which results were obtained, namely:

- Uniformity: considering all the weights distributed equally.
- Reduction: maintaining the importance of the greatest criterion and reducing the values of the others.
- Inversion 1: inverting the order of the scenario considered, giving greater importance to the second criterion.
- Inversion 2: inverting the order of the scenario, giving greater importance to the second criterion and reducing the rest.

From the results processed by Decision Lab the following conclusions could be reached:

- In all the scenarios tested, the net flows are not practically altered. this shows a tendency for small alterations in the order of the alternatives and values of the flows.
- The cut-off line between positive and negative flows remained constant between the options Xstrata, Rio Tinto and Anglo Gold.
- An inversion of the order was discovered between the alternatives Vale and BHP, when the option Inversion 2 was applied.
- The variations of the values of the flows were not very sensitive to changes in the weights.

In this way, it was concluded that the results obtained with the weights selected behave in a consistent way when evaluated in relation to other scenarios deemed probable.

2.3.3. Discussion of results

Applying PROMÉTHÉE II led to identifying Vale as the company that corresponds to the best result as regards the 12 criteria used in the analysis covering the areas of materials, energy, water, biodiversity, emissions, effluents and residues, and conformity. The net flow provided by that method can be visualized in Figure 1. Nevertheless, that net flow does not indicate that Vale is about 3 times better than BHP, nor that Vale is 7 times better than Xstrata. In order to confirm the rank obtained by PROMÉTHÉE II some changes have been introduced in the data. New computations were then performed as part of the sensitivity analysis.

The generalized criterion of type I (usual) was used in this application of PROMÉTHÉE II [Brans and Mareschal, 2002]. The experts agreed that the Type I preference function should be used in the evaluation of environmental impact, since a situation of indifference would only be identified between the performances of alternatives if their values were equal. As long as a difference exists there is a strict preference for the alternative with a higher performance. This contributes to minimizing the values of indicators thus characterizing a lower environmental impact in the region of the mineral venture. No corporate parameter is then set because reducing the environmental footprint is always sought in mining operations. It is desirable that that footprint be kept as low as possible.

Conclusions

Indicators of environmental sustainability need to be aggregated without the loss of precious information. That aggregation provides an effective evaluation of environmental performance. The multicriteria analysis performed through the use of PROMÉTHÉE II allowed to identify the level of environmental sustainability of the major players in the mining industry. The selection of some specific indicators led to capturing potential problems in a clear and concise way. A higher degree of transparency associated with that level of environmental sustainability was thus provided.

The experts in different aspects of the mining industry that participated in the evaluation concluded that the application of PROMÉTHÉE II was useful in the context analyzed. It helped to aid the decisions involved in the case studied, because it combined a form of classifying alternatives – the main mineral companies – by market value, with results of environmental performance based on internationally recognized methodology accepted by the risk classification agencies of the market. Among the best results obtained by the implementation of the method the following can be cited: the construction of an organized way to think about the environmental performance of the main global players in the mining sector. and the possibility of disclosure with greater transparency for Vale shareholders, risk classification agencies and other stakeholders, by means of a structured methodology, in this way avoiding loss of precious time without a meaningful practical result. From the initial construction of the table of alternatives, criteria and weights the alternative solutions could be shared and easily understood, with their validation obtained in a very practical manner. The results were simulated by variations of weights, based on the importance attributed to the environmental performance criteria.

With respect to the practical questions related to the application of the method, chiefly in terms of the results processed, it was possible to conclude its applicability, through the result of the net flows of PROMÉTHÉE II tested in sensitivity analyses. This permits a clear view of the fluctuations as regards the modifications of the values associated with the weights. In addition to this, data processing through the Decision Lab software permitted a simple approach to the problem, based on sensitivity analyses, which led to objective and easily understood results. In this particular case study, one observed limitation was lack of information related to the environmental performance indicators of the companies, meaning that the method assumed null values, not due to operational excellence in a determined topic. With respect to the absence of information on some environmental indicators, the perception of the risk agencies as regards the environmental performance of Vale improved, confirming the need to provide the interested parties in the company, quantitative information and a minimum of conjectures not adequately founded on its environmental sustainability. The conclusion was reached that the application of the PROMÉTHÉE II method managed to fulfill its objective completely in the sense of organizing a complex decision making process, which presupposes interactivity and simulations arriving at a result which provided transparency to the effectiveness of the environmental management of the main players in the global mining industry.

The multicriteria evaluation study presented in this paper can be complemented in the future by considering the other environmental indicators of the GRI, even those of a qualitative nature (described by specific actions of environmental management), associating perhaps the Verbal Decision Analysis approach [Larichev and Moshkovich, 1997. Gomes, Moshkovich and Torres, 2010] with PROMETHÉE II. This work would provide a wider ranging evaluation of the environmental management of the mining companies and thus make an evaluation in terms of sustainability more representative.

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References

Belton V., Stewart T.J. (2002): *Multiple Criteria Decision Analysis: an Integrated Approach*. Kluwer, Boston.

Bouyssou D. (1990): *Building Criteria: A Prerequisite for MCDA*. In: *Readings in Multiple Criteria Decision Aiding*. Edited by C.A. Bana e Costa. Springer--Verlag, Berlin, pp. 58-80.

Brans J.P., Mareschal B. (2002): *PROMÉTHÉE-GAIA: une méthodologie d'aide à la decision en présence de critéres multiples*. Éditions de L'Université de Bruxelles, Bruxelles.

Citigroup Inc. (2011). http://www.citigroup.com/citi/homepage/ (19.10.2011).

Esteves A.M. (2008): *Mining and Social Development: Refocusing Community Investment Using Multi-Criteria Decision Analysis*. "Resources Policy" 33, pp. 39-47.

Figueira J., Greco S. and Ehrgott M. (2005): *Introduction*. In: *Multiple Criteria Decision Analysis: State of the Art Surveys*. Edited by J. Figueira, S. Greco, and M. Ehrgott. Springer Science + Business Media, New York.

Gallopin G.C. (1996): *Environmental and Sustainability Indicators and the Concept of Situational Indicators. A System Approach*. "Environmental Modeling & Assessment", Vol. 1, pp. 101-117.

Goldman Sachs (2011). http://www.goldmansachs.com (19.01.2011).

Gomes L.F.A.M., Moshkovich H. and Torres A. (2010): *Marketing Decisions in small Businesses: How Verbal Decision Analysis Can Help*. "International Journal of Management and Decision Making", Vol. 11, No. 1, pp. 19-36.

GRI (2009): *What is GRI*? http://www.globalreporting.org/AboutGRI/WhatIsGRI/ (23.12.2009).

Larichev O.I. and Moshkovich H.M. (1997): *Verbal Decision Analysis for Unstructured Problems*. Kluwer, Dordrecht.

Leyva-López J.C., Fernández-González E. (2003): *A New Method for Group Decision Support Based on ELECTRE III Methodology*. "European Journal of Operational Research", 148 (1), pp. 14-27

Roy B., Bouyssou D. (1993): *Aide multicritère à la décision: méthodes et cas*. Economica, Paris.

Slowinski R., Greco S., Matarazzo B. (2002): *Mining Decision-Rule Preference Model from Rough Approximation of Preference Relation*. 26th Annual International Computer Software and Applications Conference, IEEE Computer Society, Los Alamitos, pp. 1129.

Standard & Poors (2011). www.standardanpoors.com January 19, 2011.

United Nations (2000). http://www.un.org/millennium/declaration/ares552e.htm (19.01.2011).

Vilas Boas R.C., Beinhoff C. (eds.) (2002): *Indicators of Sustainability for the Mineral Extraction Industry*. CNPq/CYTED, 2002. Carajás, Brasil.

Visual Decision (2009): *Prométhée-Gaia Software. Version 1.01.0386, ULB/VLB Students*. http://www.visualdecision.com/dlab.htm (17.12.2009).

WWF-Brazil (2009): *O que é desenvolvimento sustentável?* http://www.wwf.org.br (10.12.2009).