Abstract—Information technology and the environment have a relationship until then signaled by the effects caused by excessive energy consumption, greenhouse gas emissions and the e-waste. In our paper we present the GreenRM reference model for sustainable software development. We focus on the model structure definition and the benefits identified with its implementation. We also present a comparison between the model processes and attributes with the environmental requirements of ISO/IEC 14001 to demonstrate its compatibility. In addition we present a model early assessment in three Brazilian software organizations to evaluate the model technical and financial feasibility.

Keywords: Green IT; Process Reference Model; Sustainable Development; Green Software Engineering.

I. INTRODUCTION

When we think of Information Technology (IT), words like innovation and solution come to mind. However, rarely, or never, we think on relationship between IT and the environment. This relationship is discussed through green IT, which has emerged as a subject centralizing this discussion bringing to the IT market the importance of sustainable development and the growth focused on preservation of the environment. Environmental problems associated with the IT industry are mainly related to the large power consumption, the emission of carbon dioxide and lack of treatment of e-waste [1]. In software organizations we observed that environmental issues are the same, mainly due to technological resources used and the infrastructure required. In the software life cycle we can analyze issues related to the energy consumption during the execution of programs or the energy consumption to maintain the infrastructure of the software factory (computers, servers, and others), printing documents on requirements gathering phase or the use of disposable media (CD, DVD) on the installation phase [2], the great demand for acquisition of new equipment or electronic components with higher performance and the hardware change that become obsolete when the software evolves [3].

On this research we analyze organizational changes for a software organization implement processes that contribute to the improvement and reduce of environmental problems within their organizational setting. This paper presents the GreenRM reference model to support software organizations in the effort to achieve process improvement but considering environmental quality with the introduction of environmental management. The GreenRM can stimulate competition in the software market through sustainable image, allowing organizations to be qualified and valued from an environmental quality model.

II. THE GREENRM REFERENCE MODEL

GreenRM is a reference model based on the concepts of maturity and capability and was developed based on two pillars, the PRO2PI-MFMOD method framework [4][5] and the environmental standard ISO/IEC 14001 [6]. The PRO2PI-MFMOD framework was used to establish a reference model construction method for the GreenRM development. The ISO/IEC 14001 was used as a support to identify relevant processes and practices already consolidated.

During the PRO2PI-MFMOD framework instantiation, some activities and techniques were performed: 1) Gathering environmental needs in IT and definition of the target audience; 2) Literature Review; 3) Reference model structure definition (based on ISO/IEC 15504 [7]); 4) Detailed analysis of selected models; 5) Hold meetings with experts from the ISO/IEC 15504 to ensure structure compatibility between models; 6) Development strategy review; 7) A preliminary model version was evaluated with three software organizations. These activities were developed from the "Sequential Practices" described in the framework. The techniques employed in the development were: Translation process areas of an existing model; Application questionnaire; Literature Review; Analysis of related work and Peer Review. The PRO2PI-MFMOD framework instantiation allowed the development of a reference model based on definitions and concepts of recognized and consistent models in Software Engineering. With this, we expect a greater acceptance in software organizations that already have implemented maturity and capability models for software quality. The major benefits in implementing the GreenRM model are the integration of environmental management with the business goals, financial returns arising from green solutions like energy conservation, the sustainable image, changes on processes organizational for the environmental certification ISO/IEC 14001 and the change on culture and awareness.

A. Green Levels

The green levels developed on GreenRM are the model maturity levels. Each maturity level has a set of required...
processes. In addition, the processes were also classified in three categories: main processes, organizational processes and supporting processes.

The first green maturity level (G1 - Environmental sustainability is managed) defines four processes: GSM - Green Solution Management (main); DCM - Data Center Management (main); EWM - Electronic Waste Management (main); and ERM - Environmental Risk Management (supporting). The second green maturity level (G2 - Environmental sustainability is institutionalized) defines four processes: GAQ - Green Acquisition (organizational); GEI - Green Solution Evaluation and Improvement (supporting); GSD - Green Software Development (main); and GIR - Green Software Installation and Retirement (main). The third green maturity level (G3 - Environmental sustainability is continuously improved) defines three processes: GMS - Green Solution Measurement (organizational); OTG – Organizational Training for the Green Solution (organizational); EKM - Environmental Knowledge Management (organizational).

The green level G1 ensure an organized management of environmental initiatives performed by the organization. These initiatives are identified as green solutions and are treated at the first process of the level. By means of assuring the environmental management of specific solutions for the data processing center and for the electronic waste, the second and the third processes of the level are responsible for these issues. To help identifying these green solutions, the last process of the level permits the risk and environmental impacts analysis. The green level G2 ensure that the environmental processes be incorporated to the remained organizational processes. In this level, the auditing process is established to assure that the green solutions are been performed as in order to meet the organization environmental goals. Focusing on the accomplishment of the environmental requirements related to the software lifecycle, two processes are defined. These two processes focus on environmental practices directed related to the development, installation and the retiring phases of the software. Still at this maturity level, a process for green acquisition is also defined, demanding that supplier’s selection and evaluation be based on environmental criteria. The green maturity level G3 permits to analyze and measure the benefits gained with the application of green solutions through measurement and guarantees that the knowledge acquired with green solutions implementation be managed and disseminated.

B. Capability Levels

For the GreenRM capability dimension (model evaluation), three capability levels and eleven process attributes (PA) defined for the levels from 1 to 3 are presented. The ISO/IEC 15504 and ISO/IEC 14001 standards contributed significantly to the development of these process attributes. Most of these attributes is related to the environmental management needs specified at the ISO/IEC 14001.

The level 0 is not included in any type of indicator because it represents a non-implemented process or a faulty one in accomplishing the outcomes. The capability level 1 represents the process is managed: PA1 - the process achieves its defined outcomes; PA2-formal process documentation is established, maintained and communicated to everyone involved; PA3-the process is planned and monitored; PA4-required roles and responsibilities to perform the process are identified; PA5-personnel performing the process are competent on the basis of appropriate education, training and experience; and PA6-the process is specified on the organization environmental policy. At capability level 2, it is defined that the process is institutionalized. The process attributes are then evaluated: PA7-a process improvement group is formally established to continuously discuss and revise the process; and PA8-the process outcomes are revised at different hierarchical levels of the organization, including higher level management. And finally, capability level 3 represents that the process is measured and evaluated continuously. To evaluate this level, the process attributes are demonstrated: PA9-achieved outcomes by the process performing allows demonstrating environmental benefits; PA10-process measurements are collected and analyzed in order to support the decision making about the environmental solutions; and PA11-improvement opportunities derived from technological innovations and environmental solutions are identified, evaluated and selected to support the business’ goals achievement.

The process attributes PA2, PA4, PA6, PA8 e PA10 were identified from the analysis of the environmental requirements demanded by the ISO/IEC 14001 standard. By achieving these attributes, it is possible to guarantee the existence of the environmental policy and the formalization of processes in this policy, defining the roles and responsibilities involved, the analyses of administration in the decision making, as well as measurements for identifying corrective and preventive actions.

C. A Process Documentation Excerpt

As an example of the processes documentation, we present in Table I, the G2 maturity level process GSD (Green Software Development). This process allows the analysis of environmental practices in the software development lifecycle.

<table>
<thead>
<tr>
<th>Process ID</th>
<th>GSD</th>
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<tbody>
<tr>
<td>Process Name</td>
<td>Green Software Development</td>
</tr>
<tr>
<td>Process Purpose</td>
<td>Provide the environmental performance on the activities related to the software development phase. The improvement actions allow the insertion of environmental practices on the activities that belong to the software lifecycle.</td>
</tr>
<tr>
<td>Process Outcomes</td>
<td>As a result of the successful implementation of the software:</td>
</tr>
<tr>
<td>1.</td>
<td>Software documentation is developed in electronic media and tools for traceability are established.</td>
</tr>
<tr>
<td>2.</td>
<td>The useful life of the software is analyzed at the requirements survey phase, considering future needs and current hardware limitations.</td>
</tr>
<tr>
<td>3.</td>
<td>Non-functional requirements aiming at meeting environmental needs are specified.</td>
</tr>
<tr>
<td>4.</td>
<td>The prototypes elaborated at the requirements survey phase are reused on the software implementation.</td>
</tr>
<tr>
<td>5.</td>
<td>Modularization practices are used in the software project, when necessary.</td>
</tr>
<tr>
<td>6.</td>
<td>The software components and methods are projected aiming their reutilization.</td>
</tr>
<tr>
<td>7.</td>
<td>Automation tools are used in the software implementation stage.</td>
</tr>
<tr>
<td>8.</td>
<td>Unit tests are performed in the end of each implementation.</td>
</tr>
<tr>
<td>9.</td>
<td>Automated tests are planned and performed according to the frequency established in the planning.</td>
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</table>
have understood that environmental quality complements software quality.

When implementing the GreenRM in software organizations, this process is mandatory and also should be evaluated in relation to the process attributes defined in each capability level.

III. THE ISO/IEC 14001 AND THE GREENRM

The Brazilian government has been prioritizing organizations that implement the environmental management system or any of the environmental requirements defined by the ISO/IEC 14001 standards. In some public notices for hiring software services - Petrobrás (Brazilian Oil Company) is a good example - it is possible to find items that demand the meeting of at least one requirement in the standard.

To support the ISO/IEC 14001 implementation in software organizations, the GreenRM has been developed to provide a path for this environmental certification. The standard describes the requirements that the environmental management system should meet; however, there is no script or guide that helps the application of these. The GreenRM supports the implementation of these requirements through the establishment of a model that presents in details what should be done and provides a complementary implementation guide that allows a more detailed understanding of each environmental process.

The ISO/IEC 14001 standard presents generic requirements, not considering specific aspects of information technology and software engineering. The GreenRM tries to fill this gap, establishing specific processes and practices to improve software development organizations. The conception of a model based on ISO/IEC 14001 qualifies and brings a strong basis to the model processes. Through Table II evaluation it was possible to realize that GreenRM meets the environmental requirements specified in the standard. However, it is necessary a previous evaluation of the organization before the certification because there are elements such as the documents content which were inserted only as work products in the GreenRM. This includes specifically the item ‘4.4.4 Documentation’.

IV. GREENRM ASSESSMENT

To evaluate the model, an interview process to assess technical and financial feasibility of the GreenRM implementation has been done in three software organizations (Table III) with the participation of software engineering and environmental management experts.

<table>
<thead>
<tr>
<th>TABLE II. SOFTWARE ORGANIZATIONS EVALUATED</th>
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<tbody>
<tr>
<td>A. Software development organization with 20 years of existence; 900 workers; MPS C (Brazilian Model equivalent to CMMI-DEV ML 3).</td>
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<tr>
<td>B. Software development organization with 34 years of existence; 700 workers; CMMI-DEV ML 2.</td>
</tr>
<tr>
<td>C. Software development organization with 10 years of existence; 200 workers; CMMI-DEV ML 2.</td>
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</table>

Concerning the technical feasibility, the three organizations considered the model a feasible one. However, the Green Acquisition and Green Solution Measurement processes have

All expected process outcomes are related to environmental base practices. It is also possible to notice that these expected outcomes consider software quality aspects. Thus, we have concluded that environmental actions employed on the green software development process also contribute for software quality in general. This allows the organization to improve its development processes aimed at environmental quality and, at the same time, to improve the software itself. In this sense, we
been questioned by the organization A. The interviewee explained that the Green Acquisition process implementation would be problematic because of difficulties in finding and choosing suppliers from environmental criteria, taking into consideration that there might be a reduced number or even no organizations that put environmental actions into practice, and this would limit their choice of good suppliers. For the Green Solution Measurement, the interviewee has considered this a more difficult process to implement because, nowadays, difficulties already took place when measurements are done in the organization.

Regarding the financial feasibility, the model was considered feasible for the three organizations. Excepting for the Data Processing Center process evaluated as unfeasible by organization C, since it has its infrastructure outsourced. However, in situations like that, where an organization can justify the absence of a data center, the GreenRM model allows the exclusion of the DCM process. The evaluation process also identified how the results have been met for each process: N-Not Achieved; P-Partially Achieved; L-Largely Achieved; and F-Fully Achieved.

Through this collection, it has been identified the reaching level of the process in relation to the PA 1 attribute - in which the process reaches its defined outcomes. This was the only process attribute evaluated, since the evaluation aimed at identifying the processes adherence to the organizations reality. The evaluation of the PA 1 process has been considered as a first step, only to identify whether the organization executes a given result or not. Besides, it was not possible to evaluate the other attributes of the process, because the organizations did not implement the model.

To determine the process capability, the ISO/IEC 15504-3 evaluation method considers that each process attribute is assessed on a four-point (N-P-L-F) rating scale: Not achieved (0 - 15%); Partially achieved (>15% - 50%); Largely achieved (>50% - 85%); and Fully achieved (>85% - 100%). The rating is based upon evidence collected against the practice indicators, which demonstrate fulfillment of the process attribute.

Through this analysis, it has been identified that organization A and C have not obtained processes evaluated at the 'Fully achieved' level, while organization B has obtained two processes in this level. Regarding the 'Largely achieved' level, it has been identified that organization A has obtained two processes, organization B has obtained five processes and organization C has obtained one process in this level. For the 'Partially achieved' level, it has been identified that organization A and C have obtained two processes, while organization B has not obtained any process in this level. And, concerning the 'Not achieved' level, the organization A has obtained seven processes, organization B has obtained four processes and organization C has obtained eight processes in this level.

From the result of this evaluation, it was possible to compare the evaluated organizations. The organization B stands out from the others, which made possible to conclude that this organization will succeed best when implementing the model, taking into account that organization B holds more processes in the 'Fully achieved' and 'Largely achieved' levels than the others. Therefore, on the comparative presented by the graph, the organization B is in the first position, organization A is in the second and organization C is in the third position.

In most cases, the actions applied by the organizations are motivated by their own interests, since most of the times there are no support from the Brazilian government in environmental projects for this area. Thus, we understand that investments in establishing projects such as the GreenRM will be possible when the government starts to grow interest and demand on the public hiring processes, providing the appreciation of software organizations that implement environmental actions.

V. CONCLUSION

Our research demonstrates that GreenRM is a model that unites the concepts of Green IT in software development organizations with the ISO/IEC 14001 environmental requirements, according to the reality of these organizations. The GreenRM can be used as a guide for the environmental certification and for the application of Green IT practices. The main goal is not just support practices related to infrastructure but also improve the environmental sustainability in the software development process. The model has been evaluated in three software organizations obtaining supportive results. However, we realize that these results cannot be generalized. It is necessary to expand the evaluation considering a larger number of software organizations and also evaluate the model with a group of Green IT experts from Brazil and abroad.

We also are negotiating to work in a pilot for the model implementation in a software organization. The results of this implementation will allow a real verification of the GreenRM, including a complete review of the model. In addition we are also working with a metrics model to support the implemented practices measurement allowing to verify not just if the organizations are achieving the outcomes defined by the GreenRM, but if the implementation achieves real environmental benefits to this organizations.

REFERENCES