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Application of ISO/IEC 33000 to Green IT: A Case Study

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ABSTRACT Sustainability is increasingly present in all areas of society and organizations. In Information Technology (IT), the idea of sustainability has come through the so-called Green IT practices. These practices are attracting many organizations that have realized the importance of this area and the benefits it generates socially, economically, and environmentally. However, there is a lack of standards and/or frameworks that help organizations to carry out these Green IT practices. For this reason, we have developed the *"Governance and Management Framework for Green IT"* and an ISO/IEC 33000-based maturity model for this framework, which allow to perform the implementation, evaluation, and improvement of Green IT in organizations in a systematic and progressive manner. In the present study we present an empirical validation through a case study that we have conducted with these proposals, emphasizing the application of ISO/IEC 33000 family of standards to Green IT. The results obtained in this case study demonstrate the importance of having a maturity model for Green IT and the validity and usefulness of the application of ISO/IEC 33000 to Green IT through the developed maturity model.

INDEX TERMS ISO/IEC 33000, maturity model, sustainability, green IT, governance, management, audit, case study.

I. INTRODUCTION

Sustainability [1] has "landed" on society and organizations, and it is here to stay indefinitely. The pressing need to take care of the environment and turn development and progress into responsible and sustainable is vital for survival in all areas. However, there is still a large part of society and of organizations that are either not aware of this idea, or do not have the necessary tools or resources to carry it out.

From the point of view of the organizations, there are more and more examples that demonstrate the importance of carrying out environmentally friendly practices and the enormous benefits that sustainability generates [2]–[4]. One of the business areas that is being considered most (due to its impact and relevance) to carry out sustainable practices is the area of Information Technology (IT). However, in this area, organizations are faced with too high obstacles when they decide to start implementing the so-called Green IT practices [5]–[7]. This is because they have to investigate and experiment with this type of practices on their own, since there are no wide adopted and validated standards and/or frameworks that help them carry out accurate implementations in this regard [8]–[10].

Given these premises, we developed the *"Governance and Management Framework for Green IT"* (GMGIT, from now on) [11], [12], through which organizations have a framework

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that guides them in the implementation, evaluation, and improvement of Green IT, from the governance and management of this area. After conducting a series of validations with the first version of this framework (GMGIT 1.0) [11], we realized the need to develop a maturity model that would allow to perform the entire process of implementation, evaluation, and improvement of the Green IT practices defined in the GMGIT in a progressive and systematic manner. Thus, we developed a first approach through an ISO/IEC 15504-based maturity model for the GMGIT [13], [14]. After further validating and refining these proposals, we have obtained a second version of the framework, the GMGIT 2.0, as well as a maturity model updated to the new ISO/IEC 33000 family of standards [12], [15].

Currently, we are working to validate and improve these new proposals, through empirical validations based on case studies. In fact, we have already conducted a first case study in a Spanish organization [16]. In the present article we aim to present further case study based on a Green IT audit performed in a Colombian organization, focusing on the ISO/IEC 33000-based maturity model developed for the GMGIT 2.0. Through this case study we have managed, on the one hand, to internationalize the validation of the developed maturity model, and, on the other hand, to obtain new lessons learned and evidences that demonstrate the usefulness and need to further develop and improve both the maturity model and the framework developed.

The rest of this paper is organized as follows: Section II contains the background on the area of Green IT maturity models, as well as the maturity model under validation; Section III describes the research methodology followed for the case study; Section IV shows the results obtained through the Green IT audit conducted; Section V discusses the findings and threats to validity; and, finally, Section VI presents the conclusions and lines of future work.

II. BACKGROUND

In [14] a Systematic Mapping Study (SMS) in the area of maturity models of sustainability and of Green IT is included. Through this SMS, the limited number of Green IT maturity models that currently exist is demonstrated, since only 9 related studies have been found. Likewise, it also shows the need to validate the maturity models, since only 3 of the 9 Green IT-related studies are validated [17]–[19]. Thus, the results of this SMS demonstrate the youth of this area and the lack of a consistent and validated Green IT maturity model.

That is why, after having analyzed the state of the art of the Green IT maturity models and considering the results and deficiencies found in the SMS, we performed the development of a first version of a maturity model for Green IT (through the GMGIT 1.0 [11]) based on the ISO/IEC 15504 family of standards [14].

However, the ISO/IEC 15504 [13] has been replaced by its successor, the ISO/IEC 33000 [15]. The changes that have been made in this new standard are mainly based on the clarification and inclusion of new concepts to make a standard more open and with a greater range of application than its predecessor.

So, after conducting a series of validations with the first versions of the GMGIT and of the maturity model developed for this framework, we not only refined and improved both, but we also carried out the updating of the maturity model to the new standard, obtaining in this way the ISO/IEC 33000-based maturity model for the GMGIT 2.0 [12].

This new maturity model consists of a total of 5 maturity levels, among which are divided the 35 processes of governance and management of Green IT that includes the GMGIT 2.0.

Likewise, this maturity model includes the description of each of the 35 processes following the process attributes defined by the ISO/IEC 33000, as shown in TABLE 1 through the example of the BAI09 process.

And, on the other hand, this maturity model also includes the characteristics that must be considered to evaluate the capability of each process. For this, the same 5 capability levels, process attributes, and results of the process attributes established by the ISO/IEC 33000 have been adopted. In this sense, Figure 2 shows the relationship between the established levels of capability and of maturity, through which we can see with what capability level(s) of the processes must be fulfilled at the time of obtaining a certain maturity level of Green IT.

Last but not least, it is important to highlight that ISO/IEC 33000 establishes (through the ISO/IEC 33004 standard [20]) the guidelines/requirements to develop models for specific areas based on that family of standards. When developing the specific maturity model for the GMGIT 2.0, we have followed these guidelines and we can affirm the following with respect to these:

- **Processes.** The established processes are correctly defined based on all the process attributes that the standard identifies, establishing all the necessary characteristics to achieve the purpose of each process (cf. Figure 1).
- **Maturity.** The maturity levels established by the standard have been adapted to the Green IT maintaining the same logic and base. Likewise, at each maturity level, a series of processes have been established according to their complexity and suitability for each level (cf. Figure 2).
- **Capability.** The capability levels, as well as the process attributes and results of these process attributes have been adopted as established by the ISO/IEC 33000; so there are no possible discrepancies in this regard (cf. Figure 2).

III. CASE STUDY RESEARCH METHODOLOGY

A. CASE STUDY APPROACH

A case study is *"an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially*

TABLE 1. Compliance with processes and their practices of Level 1 of maturity in the UCEVA.

Processes and their Base Practices of Level 1 of Maturity	Yes	Partially	No
BAI09: Manage assets	**X**		
BAI09.BP1: Identify and record current assets	X		
BAI09.BP2: Manage critical assets	X		
BAI09.BP3: Manage the asset life cycle	X		
BAI09.BP4: Optimize asset costs	X		
BAI09.BP5: Manage licenses	X		
DSS01: Manage operations		**X**	
DSS01.BP1: Perform operational procedures	X		
DSS01.BP2: Manage outsourced services	X		
DSS01.BP3: Monitor IT infrastructure			X
DSS01.BP4: Manage the environment			X
DSS01.BP5: Manage facilities			X

BAI09: Process Attributes with respect to the ISO/IEC 33000-based Maturity Model for Green IT

Attribute	Description	
ID	BAI09	
Name	Manage assets	
Description	Manage the IT assets through the life cycle to ensure that their use adds value to optimal cost, that they will remain functioning (in harmony with the objectives), that they are justified and protected physically, and that those assets which are critical in supporting the capacity of the service are reliable and available. Manage the software licenses to ensure that the optimal number is acquired, and that they are maintained and rolled out as is deemed necessary for the business; the software installed must comply with the license agreements.	
Purpose	Account for all the IT assets and optimize the value provided by these assets.	
Results	As a result of the successful implementation of "Manage assets": 1. Ensure that all the assets acquired fulfill the requirements of Green IT and that their use conforms to the policies, principles and goals of Green IT.	
Base practices	**BAI09.BP1: Identify and record current assets.** Keep an up-dated and precise record of all the assets of Green IT and related to/affected by Green IT and that are needed for the provision of services, as well as assuring their alignment with the configuration and financial management. [Result: 1] **BAI09.BP2: Manage critical assets.** Identify the assets of Green IT and related to/affected by Green IT that are critical in the provision of service capacity, and take steps to maximize their reliability and availability in supporting business needs. [Result: 1] **BAI09.BP3: Manage the asset life cycle.** Manage the assets of Green IT and related to/affected by Green IT from their acquisition until their elimination to ensure that they are used as effectively and efficiently as possible, and that they are registered in the accounts and protected physically. [Result: 1] **BAI09.BP4: Optimize asset costs.** Review the whole base of assets of Green IT and related to/affected by Green IT regularly to identify ways of optimizing costs and of maintaining alignment with the business needs. [Result: 1] **BAI09.BP5: Manage licenses.** Manage the licenses of software related to/affected by Green IT, such that there is always an optimal number of these to support the business requirements and to guarantee that the number of licenses owned is enough to cover the software installed and in use. [Result: 1]	
Work products	**Inputs**	**Outputs**
	Inventory of the organization's assets. [Result: 1]	Inventory of assets of Green IT. [Result: 1]
	Inventory of assets of Green IT. [Result: 1]	Levels of criticality of assets of Green IT. [Result: 1]
	Levels of criticality of assets of Green IT. [Result: 1]	Alignment of the requirements and guidelines of Green IT with the procedures of use and management of the assets of Green IT. [Result: 1]
		Corrective actions to optimize the costs of the assets of Green IT. [Result: 1]
		Register of licenses for software related to/affected by Green IT. [Result: 1]

FIGURE 1. Process attributes of the BAI09 process in the ISO/IEC 33000-based maturity model for the GMGIT 2.0.

when the boundaries between phenomenon and context are not clearly evident" [21].

That is why we have decided to use this type of empirical validation since it is a very appropriate methodology to verify that a certain proposal is applicable and useful in practice and/or real contexts. Thus, following the guidelines defined by Runeson and Höst [22], [23], we established the following exploratory research questions, in order to achieve the

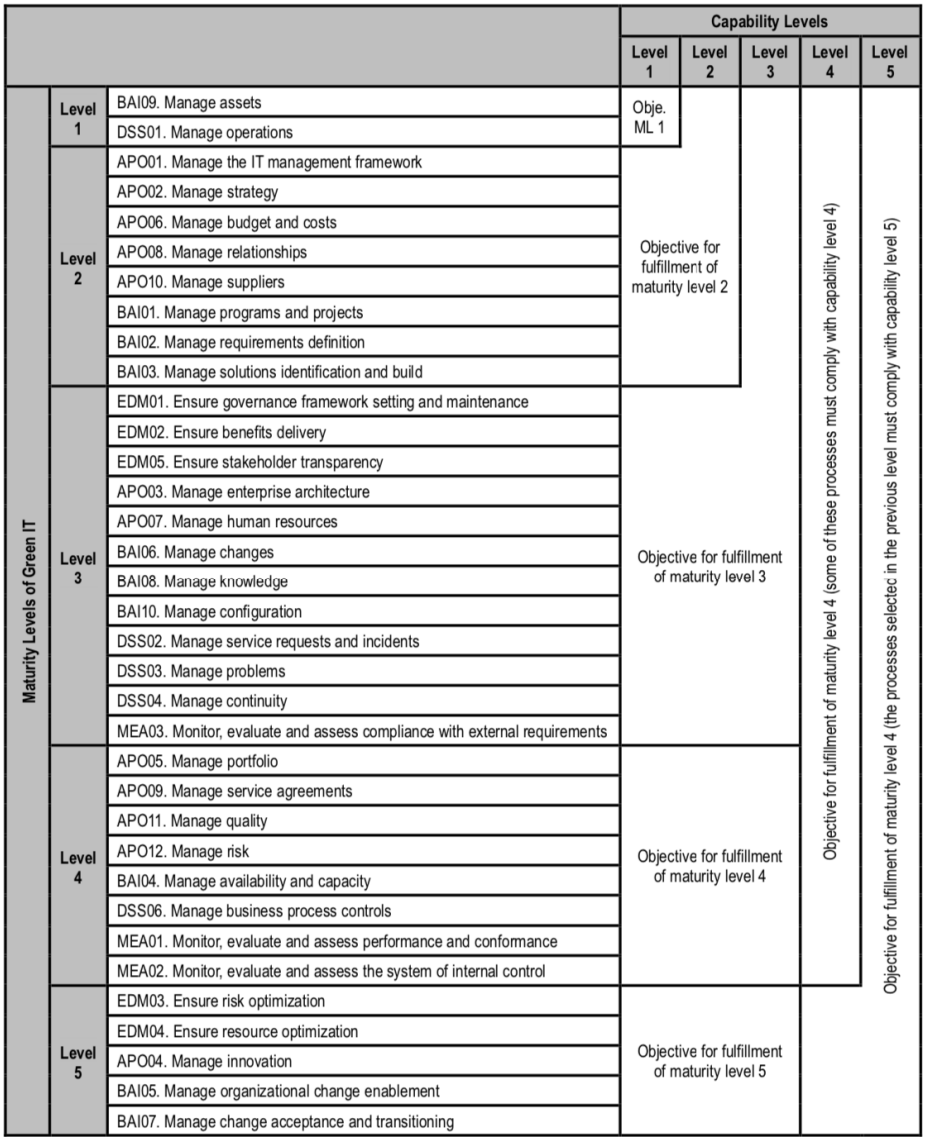

FIGURE 2. **Relationship between maturity levels and capability levels in the ISO/IEC 33000-based maturity model for the GMGIT 2.0.**

research goal to validate and refine the ISO/IEC 33000-based maturity model developed for the GMGIT 2.0:

- **RQ1:** Is the ISO/IEC 33000 family of standards adequate to develop a specific maturity model for Green IT?
- **RQ2:** Are the processes at a correct maturity level with respect to the organizational initiatives?
- **RQ3:** Are the ISO/IEC 33000-based maturity model for the GMGIT 2.0 applicable in real contexts?

B. CASE SELECTION

When selecting the organization to carry out the case study, we have considered different aspects in order to select and appropriate and representative case.

First, the case studies that we conducted with the previous versions of the GMGIT and of the maturity model [11], [14] were carried out in different Spanish organizations that provide IT services to several universities. So, in order to maintain a certain level of correlation and parallelism, we decided to continue with this same type of organization, but this time in a different country, which helps us to internationalize the validations. Therefore, we chose the IT services center of the Central Unit of Valle del Cauca (UCEVA, from now on), a Colombian university with approximately 6,000 students and 500 professors and researchers.

On the other hand, when selecting the UCEVA, we not only considered the above, but we also analyze if it was a representative case from the point of view of the sustainable practices that they carry out. Currently, the UCEVA is working on a project to reduce the carbon footprint (CO_2) that IT produces. With this goal, they have begun to implement a first sustainable practices in this regard:

- Sustainable IT acquisitions (following the regulations and acceptable levels of consumption of IT equipment, through the Energy Star standard).
- Automatic shutdown of computers and other IT devices.
- Configuration for all the computers and IT devices to adjust the brightness level to adequate levels for its use and energy consumption.
- Handbook of recommendations and awareness about the proper use of IT, such as keeping peripheral devices that are not used turned off, do not forget to turn off all the devices at the end of the working day, etc.

C. DATA COLLECTION

The present case study is based on a Green IT audit, so the data collection has been carried out following a qualitative methodology (the only possible in this type of case studies) through interviews, observations, and collection of documents.

Thus, the Green IT audit at the UCEVA was conducted during October-November 2018, following and applying the GMGIT 2.0 and the ISO/IEC 33000-based maturity model developed for this framework [12].

During the audit process, first, we conducted an interview with the UCEVA managers, in order to determine the audit scope, as well as to obtain general information about the organization such as mission, vision, activities, etc. From this first interview we obtained information about the Green IT practices carried out by the UCEVA (explained in the previous subsection) and we determined that a specific audit of *Green in IT* was going to be performed. This is because the Green IT practices carried out by the UCEVA are based on reducing the negative impact that IT itself has on the environment. To clarify this term, the definitions of the two perspectives that can be found in Green IT [24] are shown below:

- ***Green in IT*:** when the IT itself has an impact on the environment, due to its energy consumption and to the emissions it produces, and this impact should be reduced (i.e., IT as producer).
- ***Green by IT*:** in the sense that the IT provides the tools needed to allow different kinds of tasks to be carried out in a sustainable way with the environment (i.e., IT as capacitator or enabler [25]).

On the other hand, also from this first interview, we decided to include only the first two maturity levels in the audit scope, analyzing in detail and ensuring the implementation of the processes of these levels before analyzing and implementing more complex levels (although some characteristics of these higher levels have also been analyzed, but in less detail). It is important to highlight that this is the first contact with the UCEVA in an improvement process, through which we first intend to know what the situation of the organization at the most basic levels is, in order to address the deficiencies that exist in the most important processes before implementing and evaluating more mature and complex processes.

Once all the above was established, following the audit process, we conducted a series of interviews with the main managers of the UCEVA and we collected different evidences through documents and information about the organization itself and Green IT (policies, strategies, goals, services, organizational structures, etc.). Likewise, during these interviews we filled out a checklist formed by all the *Green in IT* audit questions to be performed for the first two maturity levels, through which it is possible to observe the compliance or not of the UCEVA with the different practices of the processes of the maturity levels audited.

D. DATA ANALYSIS

Regarding the data analysis, it is important to highlight three main phases:

- **Audit planning.** This phase is related to the first interview that was carried out with the UCEVA managers (described in the previous subsection), through which the organization itself was analyzed (mission, vision, objectives, activities, etc.) to determine the audit scope. As a result of this phase, a Green in IT audit plan was elaborated, which specified the interviews to be carried out in the next phase, the people involved, and the necessary evidence to review.
- **Evaluation process.** In this evaluation phase, several interviews were held with the UCEVA managers, as well as the collection of evidences through observations, collection of documents, etc. To facilitate the analysis of all this data and information collected, during the evaluation we filled out a checklist composed by the audit questions of Green in IT of the processes of the first two levels of maturity (with possible answers: yes, no, and N/A). Likewise, in each question (if applicable and necessary), we included comments and the evidences that demonstrate the reason of the answer. After carrying out the evaluation itself, we performed the detailed analysis of all this information (checklist, comments, and evidences) and we developed the audit report. In this report, we identified the strengths and opportunities for improvement in Green IT for the UCEVA in a general way, as well as, for each of the processes audited, we also identified the non-conformities found and possible solutions to solve them.
- **Presentation of audit results.** In this last phase, we presented the audit report to the UCEVA and we analyzed all the results obtained together with them to verify their correctness and obtain a feedback from the organization about the whole process, as well as to develop an improvement plan in this regard. Also, at the end of this phase we conducted the analysis and response of the research questions, considering as input all the information obtained from the audit, as well as the comments and feedback of the members of the UCEVA.

Strengths	Opportunities for Improvement
• Existence of a sustainable initiative, through which practices to reduce the carbon footprint generated by computer equipment are being carried out. These initial Green IT practices implemented are the following: ○ Sustainable IT acquisitions (following the regulations and acceptable levels of consumption of IT equipment, through the Energy Star standard). ○ Automatic shutdown of computers and other IT devices. ○ Configuration for all the computers and IT devices to adjust the brightness level to adequate levels for its use and energy consumption. ○ Handbook of recommendations and awareness about the proper use of IT, such as keeping peripheral devices that are not used turned off, do not forget to turn off all the devices at the end of the working day, etc. • Measurement and calculation about the energy consumptions that IT equipment supposes, which strengthens and helps the implementation, evaluation and improvement of the sustainable practices that are carried out, as well as those possible future practices.	• Low level of commitment and awareness on the part of all the members of the organization and relevant stakeholders. So, it is essential to raise awareness among members (senior management, managers, etc.) and other relevant stakeholders, in order to obtain their commitment and support in this area of sustainability and Green IT. • Absence of official documents regarding the policies, strategies, objectives and other enablers of Green IT. So, the formalization of these aspects is necessary, through which the governance and management bases of Green IT will be strengthened, which will allow a more effective and efficient implementation of the practices in this regard. • The implementation of the practices of Green IT has been carried out following the own criteria of the organization. So, it is highly advisable to adopt some framework or standard to guide these implementations throughout their whole life cycle, which will increase the level of success and the improvement of the practices carried out in this regard. • Poor number and limited scope of the practices of Green IT, since they are based exclusively on reducing the energy consumption of the IT equipment. So, it is recommended to investigate and analyze new and possible practices of Green IT, such as the use of virtualization, the recycling of obsolete electronic material, or the reduction of the number of printers through a centralized printing service, among others.

FIGURE 3. General results of the green in IT audit at the UCEVA.

DSS01. Manage Operations	
Non-conformity	**Possible Solutions**
It is not supervised that the IT infrastructure and all those sustainable elements/aspects of it are correctly adapted to the Green IT.	• Ensure that sustainable aspects of the IT infrastructure are monitored, such as the operations and use of sustainable solutions in IT, the optimal use of IT resources, etc., ensuring their correct adaptation to Green IT.
The requirements of *Green in IT* in the management of the environment and in the management of the facilities are not considered.	• Ensure that the management of the environment considers and complies with the requirements of *Green in IT*. • Ensure that the management of the facilities considers and complies with the requirements of *Green in IT*.

FIGURE 4. Non-conformities and possible solutions in the DSS01 process of level 1 of maturity of green in IT for the UCEVA.

IV. CASE STUDY RESULTS

After conducting the entire evaluation/audit process of Green in IT in the UCEVA (evaluating the processes of the first two maturity levels), we developed the audit report. In this audit report, we first identified a series of general results through the strengths and opportunities for improvement in Green IT for the UCEVA (see Figure 3).

In the same way, in the audit report we also identified process by process audited the non-conformities found and possible solutions to solve them, as can be seen in Figure 4 through the example of the DSS01 process of Level 1 of maturity.

Therefore, after analyzing all the results in detail obtained in the *Green in IT* audit conducted in the UCEVA and following the ISO/IEC 33000-based maturity model developed for the GMGIT 2.0, we concluded that the UCEVA is partially at Level 1 of maturity of *Green in IT*. This is reflected in Table 1, which shows the compliance of the UCEVA with the processes and their practices of Level 1 of maturity. Likewise, Table 2 also demonstrates this result through the evaluation of the capability of each one of the audited processes of the first two levels of maturity.

V. DISCUSSION

A. MAIN FINDINGS

After analyzing the results obtained in the present case study and considering the research goal of validate and refine the ISO/IEC 33000-based maturity model developed for the GMGIT 2.0, we have reached the following findings:

- **ISO/IEC 33000-based maturity model developed for the GMGIT 2.0.** Thanks to this empirical validation we have been able to put into practice this maturity model. Through the results and feedback obtained, we have reinforced the validity and usefulness of both this maturity model and the GMGIT 2.0 itself when implementing, evaluating, and improving the Green IT in a progressive and systematic manner. We have also observed that this new version of the maturity model maintains the coherence with respect to the previous version.

TABLE 2. Compliance of the audited processes with the process attributes (PA) and their results (PAR) of levels 1 and 2 of capability in the UCEVA.

Process Attributes (PA) and their Process Attributes Results (PAR) of Levels 1 and 2 of Capability	BAI09	DSS01	APO01	APO02	APO06	APO08	APO10	BAI01	BAI02	BAI03
PA 1.1: Process performance	**F**	**P**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
The PARs of PA 1.1 correspond to the results of the process on which it applies										
PA 2.1: Process performance management	**P**	**P**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
PAR 2.1.1: Determine and communicate the results to be achieved	F	P	N	N	N	N	N	N	N	N
PAR 2.1.2: Determine and address the risks that may affect the performance of the process	F	P	N	N	N	N	N	N	N	N
PAR 2.1.3: Plan, monitor, measure, evaluate, and adjust the performance of the process	F	N	N	N	N	N	N	N	N	N
PAR 2.1.4: Define, assign, and communicate those responsible and authorities to perform the process	P	P	N	N	N	N	N	N	N	N
PAR 2.1.5: Determine, provide, and maintain the necessary resources to perform the process	F	P	N	N	N	N	N	N	N	N
PAR 2.1.6: Determine the competencies to perform the process	P	N	N	N	N	N	N	N	N	N
PAR 2.1.7: Ensure the competences of the people who perform the process on the basis of an appropriate education, training or experience	P	N	N	N	N	N	N	N	N	N
PAR 2.1.8: Manage the interfaces between the parties involved to ensure effective communication and level of control expected	P	N	N	N	N	N	N	N	N	N
PA 2.2: Work products management	**P**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
PAR 2.2.1: Determine the requirements for work products	P	N	N	N	N	N	N	N	N	N
PAR 2.2.2: Define the requirements for the control of work products	P	N	N	N	N	N	N	N	N	N
PAR 2.2.3: Identify, document, and appropriately control work products	P	N	N	N	N	N	N	N	N	N
PAR 2.2.4: Review and approve the suitability and adequacy of the work products in accordance with the defined plans and adjust them as necessary to meet the requirements	P	N	N	N	N	N	N	N	N	N
PAR 2.2.5: Determine, maintain and preserve work products to provide confidence that the process is carried out in the manner established and thus ensure the compliance of work products and/or services with their requirements	P	N	N	N	N	N	N	N	N	N

F: Full compliance; P: Partial compliance; N: Non-compliance

- **Central Unit of Valle del Cauca.** Taking the UCEVA as an example, we have observed that organizations are increasingly committed to Green IT, but they are disoriented by the lack of reliable frameworks and/or standards that guide them. The UCEVA has seen a great opportunity to advance in this area of Green IT through the GMGIT 2.0 and the maturity model developed for this framework. Likewise, the UCEVA is very satisfied with this case study and has decided to continue working through an improvement plan following the GMGIT 2.0 and the maturity model, with the aim of reaching the Level 2 of maturity in a few months.

Likewise, as lessons learned we have identified the need to apply international standards to the GMGIT 2.0, such as the ISO 14000 [26]. This will benefit both the GMGIT 2.0 and the maturity model developed, as it will reinforce its applicability and broaden its scope towards new wide adopted best practices of the industry.

On the other hand, each of the exploratory research questions established for this case study is answered below, based on all the results obtained from the data collected.

1) RQ1: IS THE ISO/IEC 33000 FAMILY OF STANDARDS ADEQUATE TO DEVELOP A SPECIFIC MATURITY MODEL FOR GREEN IT?

The maturity and capability levels, the process attributes, and other factors and characteristics that the new ISO/IEC 33000 [15] defines, are very suitable to develop a maturity model for Green IT. All these characteristics have been very helpful not only when developing the specific maturity model for the GMGIT 2.0, but also when applying it through the case study, conducting a fully progressive and systematic process.

From our point of view as auditors, using the ISO/IEC 33000 family to develop a specific maturity model for the GMGIT 2.0 has helped us to have a clear base and concepts that have been reasonably adaptable to the processes and characteristics of Green IT defined in the framework. The ISO/IEC 33000 allows this kind of adaptations without too many complications.

Therefore, the ISO/IEC 33000 family of standards is not only adequate and applicable when developing a specific maturity model for Green IT, but it is highly recommended.

2) RQ2: ARE THE PROCESSES AT A CORRECT MATURITY LEVEL WITH RESPECT TO THE ORGANIZATIONAL INITIATIVES?

Throughout the entire case study, we have analyzed and corroborated, together with the UCEVA, the adequacy of the processes in the different maturity levels.

During the first interview we conducted during the audit planning phase, we presented the maturity model to the UCEVA managers and we asked them if they considered correct both the established maturity levels and the organization of the different processes at these maturity levels.

We analyzed the feedback obtained and confirm the adequacy of our proposal.

Likewise, during the audit itself, we were able to verify that the UCEVA considers activities of the first levels prior to performing more complex practices of higher levels. In fact, while we assessed the processes of the first two maturity levels, we also referenced to practices and activities of the processes of higher levels in order to analyze and certify in some way such higher levels and processes. During these analyzes, the UCEVA managers told us that they had not yet contemplated such practices/activities or had them partially because they are more advanced practices and they first need to ensure more basic processes.

3) RQ3: ARE THE ISO/IEC 33000-BASED MATURITY MODEL FOR THE GMGIT 2.0 APPLICABLE IN REAL CONTEXTS?

The results, findings, and feedback obtained through the case study show that the developed maturity model is clearly applicable in real-life contexts. This is also demonstrated by the high level of satisfaction of the UCEVA with this case study and its willingness to carry out an improvement plan in this respect following both this maturity model and the GMGIT 2.0.

Likewise, from our experience as auditors applying the ISO/IEC 33000-based maturity model developed for the GMGIT 2.0, our work has been simplified, since the maturity model has allowed us to assess the Green IT in a more organized and direct way.

B. THREATS TO VALIDITY

The threats to validity are analyzed below following the four aspects of validity defined by Runeson and Höst [22], [23].

1) CONSTRUCT VALIDITY

The developed maturity model is based on the well-known and wide adopted ISO/IEC 33000 [15], so there are no discrepancies between practitioners and researchers regarding the characteristics adopted from this standard. However, there may be discrepancies regarding the characteristics of Green IT, so we have tried to emphasize and explain these aspects in detail and as clearly as possible (an example is the differentiation we have made between *Green in IT* and *Green by IT*).

2) INTERNAL VALIDITY

The problems that an organization may have to carry out the case study (e.g., lack of time or resources, internal discrepancies, etc.) may pose a threat to this validity. That is why during the first interview we conducted, we analyzed the capabilities of the UCEVA (time, resources, etc.) to carry out the case study, as well as we presented the proposal to obtain the commitment of the organization and to avoid discrepancies and doubts in this regard.

3) EXTERNAL VALIDITY

The case study has been conducted in a Colombian organization dedicated to the IT services management. In order to mitigate threats regarding external validity, we are working on conducting more case studies at international level, as well as in organizations whose business models are different.

4) RELIABILITY

The analysis of the data collected during the case study has been carried out independently by each author (reducing the bias among each other). However, the authors of this study belong to close groups that work and collaborate together on different topics such as in the current case study. Thus, we are working to open both the GMGIT 2.0 and the maturity model, so that external researchers and practitioners can use and validate these proposals, mitigating in this way risks related to the reliability.

VI. CONCLUSION AND FUTURE WORK

Organizations around the world have begun to bet on the planet by carrying out sustainable practices across all business areas. Among these practices, Green IT has become a primordial basis for the sustainable growth and development of the whole business in and by IT [2]–[4]. However, organizations are disoriented due to the lack of guides that help them carry out these practices [8]–[10].

That is why we developed a first version of the *"Governance and Management Framework for Green IT"* (GMGIT 1.0) [11] and an ISO/IEC 15504-based maturity model for this framework [13], [14]. After conducting a series of validations with these first proposals, we refined and improved them, obtaining the GMGIT 2.0 and a new version of the maturity model updated to the ISO/IEC 33000 [12], [15].

Following the same dynamics of development, in this study we present an empirical validation based on a case study that we have conducted in a Colombian organization dedicated to IT services management (UCEVA), and through which we have applied the GMGIT 2.0 and, especially, the ISO/IEC 33000-based maturity model developed.

The results obtained demonstrate the growing importance that the Green IT area is taking, as well as the need and relevance of having maturity models for Green IT. Likewise, the validity and usefulness of the GMGIT 2.0 and the ISO/IEC 33000-based maturity model developed when implementing, evaluating, and improving the Green IT in a systematic and progressive manner is also demonstrated.

As lines of future work, we are working, on the one hand, on conducting an improvement plan in the UCEVA (following the ISO/IEC TR 33014 standard [27]) and more case studies in different organizations at international level, and, on the other hand, on further developing the GMGIT 2.0 through the application of relevant international standards, such as the ISO 14000 [26] (in which we are already getting some first results [27]).

The destruction of our planet has been and is one of the biggest mistakes we have committed as humankind. There is less time than we think, but we still have time to stop this destruction and achieve a sustainable and responsible development.

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REFERENCES

[1] G. Brundtland, M. Khalid, S. Agnelli, S. Al-Athel, B. Chidzero, L. Fadika, and S. Okita, *Our Common Future*. Oxford, U.K.: Oxford Univ. Press, 1987.

[2] W. Wimmer, K. M. Lee, F. Quella, and J. Polak, *ECODESIGN—The Competitive Advantage*. Dordrecht, The Netherlands: Springer, 2010. doi: 10.1007/978-90-481-9127-7.

[3] D. M. Simmonds and A. Bhattacherjee, "Green IT adoption and sustainable value creation," in *Proc. 20th Americas Conf. Inf. Syst. (AMCIS)*, 2014, pp. 2550–2565.

[4] M. Saunila, M. Nasiri, J. Ukko, and T. Rantala, "Smart technologies and corporate sustainability: The mediation effect of corporate sustainability strategy," *Comput. Ind.*, vol. 108, pp. 178–185, Jun. 2019. doi: 10.1016/j.compind.2019.03.003.

[5] C. Calero and M. Piattini Eds., *Green in Software Engineering*. Cham, Switzerland: Springer, 2015.

[6] M. Dastbaz, C. Pattinson, and B. Akhgar, Eds., *Green Information Technology: A Sustainable Approach*. Waltham, MA, USA: Morgan Kaufmann, 2015.

[7] G. Weichhart, A. Molina, D. Chen, L. E. Whitman, and F. Vernadat, "Challenges and current developments for sensing, smart and sustainable enterprise systems," *Comput. Ind.*, vol. 79, pp. 34–46, Jun. 2016.

[8] J. D. Patón-Romero and M. Piattini, "Indicators for green in IT audits: A systematic mapping study," in *Proc. 3rd Int. Workshop Meas. Metrics Green Sustain. Softw. Syst. (MeGSuS)*, Sep. 2016, pp. 4–12.

[9] C. Calero and M. Piattini, "Puzzling out software sustainability," *Sustain. Comput, Inform. Syst.*, vol. 16, pp. 117–124, Dec. 2017. doi: 10.1016/j.suscom.2017.10.011.

[10] G. A. García-Mireles, M. Á. Moraga, F. García, C. Calero, and M. Piattini, "Interactions between environmental sustainability goals and software product quality: A mapping study," *Inf. Softw. Technol.*, vol. 95, pp. 108–129, Mar. 2018. doi: 10.1016/j.infsof.2017.10.002.

[11] J. D. Patón-Romero, M. T. Baldassarre, M. Piattini, and I. G. R. de Guzmán, "A governance and management framework for green IT," *Sustainability*, vol. 9, no. 10, p. 1761, Sep. 2017. doi: 10.3390/su9101761.

[12] J. D. Patón-Romero, M. T. Baldassarre, M. Rodríguez, and M. Piattini, "A revised framework for the governance and management of green IT," *J. Universal Comput. Sci.*, to be published.

[13] *Information Technology—Process Assessment*, document ISO, ISO/IEC 15504, International Organization for Standardization, Geneva, Switzerland, 2003.

[14] J. D. Patón-Romero, M. T. Baldassarre, M. Rodríguez, and M. Piattini, "Green IT governance and management based on ISO/IEC 15504," *Comput. Standards Interfaces*, vol. 60, pp. 26–36, Nov. 2018. doi: 10.1016/j.csi.2018.04.005.

[15] *Information Technology—Process Assessment*, document ISO, ISO/IEC 33000, International Organization for Standardization, Geneva, Switzerland, 2015.

[16] J. D. Patón-Romero, M. T. Baldassarre, A. Toval, M. Rodríguez, and M. Piattini, "Auditing the governance and management of green IT: A case study," *IT Prof.*, to be published.

[17] A. Buchalcevova, "Green ICT maturity model for czech SMEs," *J. Syst. Integr.*, vol. 6, no. 1, pp. 24–36, Jan. 2015. doi: 10.20470/jsi.v6i1.220.

[18] M. Curley, J. Kenneally, and M. Carcary, Eds., "IT capability maturity framework IT-CMF," in *The Body of Knowledge Guide*, 2nd ed. Zaltbommel, The Netherlands: Van Haren Publishing, 2016, pp. 103–118.

[19] A. Hankel, L. Oud, M. Saan, and P. Lago, "A maturity model for green ICT: The case of the SURF green ICT maturity model," in *Proc. EnviroInfo 28th Int. Conf. Inform. Environ. Protection*, Sep. 2014, pp. 33–40.

[20] *Information Technology—Process Assessment—Requirements for Process Reference, Process Assessment and Maturity Models*, document ISO, ISO/IEC 33004. International Organization for Standardization, Geneva, Switzerland, 2015.

[21] R. K. Yin, *Case Study Research and Applications Design and Methods*. Los Angeles, CA, USA: SAGE, 2017.

[22] P. Runeson and M. Höst, "Guidelines for conducting and reporting case study research in software engineering," *Empirical Softw. Eng.*, vol. 14, no. 2, pp. 131–164, Apr. 2009.

[23] P. Runeson, M. Host, A. Rainer, and B. Regnell, *Case Study Research in Software Engineering: Guidelines and Examples*. Hoboken, NJ, USA: Wiley, 2012.

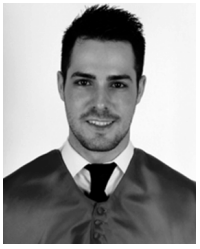
[24] K. Erdélyi, "Special factors of development of green software supporting eco sustainability," in *Proc. IEEE 11th Int. Symp. Intell. Syst. Inform. (SISY)*, Sep. 2013, pp. 337–340.

[25] B. Unhelkar, *Green IT Strategies and Applications: Using Environmental Intelligence*. Boca Raton, FL, USA: CRC Press, 2011.

[26] *Environmental Management Systems*, document ISO, ISO 14000, International Organization for Standardization, Geneva, Switzerland, 2015.

[27] *Information Technology—Process Assessment—Guide for Process Improvement*, document ISO, ISO/IEC TR 33014, International Organization for Standardization, Geneva, Switzerland, 2013.

[28] J. D. Patón-Romero, M. T. Baldassarre, M. Rodríguez, and M. Piattini, "Application of ISO 14000 to information technology governance and management," *Comput. Standards Interfaces*, vol. 65, pp. 180–202, Jul. 2019. doi: 10.1016/j.csi.2019.03.007.



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