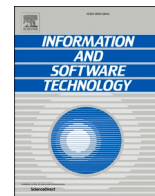




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Governance and Management of Green IT: A Multi-Case Study

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ABSTRACT

Context: The changes that are taking place with respect to environmental sensitivity are forcing organizations to adopt a new approach to this problem. Implementing sustainability initiatives has become a priority for the social and environmental awareness of organizations that want to stay ahead of the curve. One of the business areas that has, more than others, proven to be a vital asset and a potential ally of the environment, is the area of Information Technology (IT). Through this area, Green IT practices advocate sustainability in and by IT. However, organizations have a significant handicap in this regard, due to the lack of specific Green IT standards and frameworks that help them carry out this type of sustainability practices.

Objective: We have developed the "Governance and Management Framework for Green IT" (GMGIT), which establishes the necessary characteristics to implement Green IT in organizations, from the point of view of the governance and management of this area. After developing and validating a first version of this framework, we have performed a set of improvements, obtaining the GMGIT 2.0, which we want to validate.

Method: We have conducted a series of empirical validations at international level based on case studies, whose characteristics and results are presented in this study.

Results: The results of this multi-case study show an example of the current situation of organizations in Green IT, as well as the resolution of problems encountered during the validations conducted with the GMGIT 1.0.

Conclusion: The findings obtained demonstrate the usefulness, applicability, and validity of the framework when implementing, auditing, and improving Green IT in organizations in a systematic and progressive manner.

1. Introduction

The phenomenon of sustainability [1] around the world is ever more evident. Either by individual initiatives or influences (the organization itself, competence, customers, suppliers...) or collective (government, society...), organizations are increasingly pressured to, at least, catch up on basic issues of environmental management. This situation becomes visible, especially when organizations start to grow and their growth projections change, mainly because the influence of their customers and stakeholders begins to feel stronger.

Thousands of organizations, especially those that operate internationally, know that if they want to be competitive they have to incorporate sustainability practices in their productive activities [2,3]. Efforts

in this direction are far from being considered mere philanthropic acts or "green" marketing strategies; on the contrary, they are part of the business strategy and the costs are internalized as innovation to improve competitiveness [4].

Even though organizations from all over the world are registering ever more satisfactory results in terms of sustainability [5], there are still entrepreneurs who hesitate whether to get involved or stay out of, as many define it, the "green trend". The bad (or good) news for these entrepreneurs and other actors in the context of organizations and businesses, is that sustainability is here to stay, and the longer they waste, the longer it will take them to get on the wave of this necessary change. The reasons in this regard are growing, among which just to cite a few major ones:

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- **National and international laws and programs.** In many countries (France, Denmark, India...) Corporate Social Responsibility (CSR) has been institutionalized as a law and not only as a suggestion [6]. In others, the government of the state or the political community (European Union, Costa Rica...) is encouraging organizations to set goals aimed at lowering the environmental impact or the carbon footprint [7]. The incentives and tax benefits for organizations that implement Environmental Management Systems (EMS) and certify their processes in this regard are innumerable around the world. In addition, from the United Nations the slogan is clear [8]: “to achieve the millennium objectives, the productive sector must be fully involved in sustainable development”.
- **Consumers.** The tendency is that the participation of society in sustainable development issues does not stop increasing. The pressure is not only directed to the governments, but the demands for organizations to be more responsible in environmental and social issues multiply. As quality of life improves, people claim that the products they consume are of better quality, but not at the expense of degrading the environment [9]. This is not a trend, but a lifestyle that in countries with medium or high environmental awareness (such as Sweden, the Netherlands...) is fully incorporated into society, and whose example is being replicated more and more around the world.
- **Rise of Information Technologies (IT).** The advances in technological issues have been very remarkable in recent years and not only in the field of IT itself [10]. The processes of production, packaging, transport, and consumption of resources, among others, have been significantly optimized thanks to the use of more efficient machinery and devices or tools with better performance. This has allowed to reduce costs and the consumption of electricity, water, and fuel, among others. It is precisely in this evolution and rise of technologies that a decisive trend of environmental innovation known as Green IT has arisen, which advocates for the defense of the environment in and by IT and that is increasingly relevant within organizations [11, 12].

Therefore, taking these reasons and based on the importance and rise that are having IT in this regard [13], we developed a first version of the “Governance and Management Framework for Green IT” (from now on, GMGIT) [14]. This framework defines specific governance and management characteristics for Green IT. This includes principles, policies, processes, organizational structures, culture, ethics, information, infrastructure, skills, and competencies. It is defined as an add-on to the existing COBIT 5 framework [15], inheriting its structure. Further, GMGIT also contains a guide for conducting Green IT audits, and is later extended with a maturity model for Green IT [16].

With this framework we aimed to help organizations to, on the one hand, carry out a correct implementation from the point of view of the governance and management of Green IT, and, on the other hand, perform the whole audit process to corroborate the adequacy, effectiveness, and efficiency of an implementation of Green IT. Also, thanks to the GMGIT 1.0 we managed to cover the need of organizations in this context, due to the lack of standards, frameworks, and best practices (among others) in this regard [17–19].

After the development of the GMGIT 1.0, we performed a series of validations (based on case studies and focus groups), which allowed us to improve, refine, and expand the framework, thanks to the lessons learned that we obtained, resulting in a new version of the framework, the GMGIT 2.0 [16].

Following the same path as with the GMGIT 1.0, with the GMGIT 2.0 we have performed a series of validations through different international case studies. Through this multi-case study performed with the GMGIT 2.0, we have obtained promising results, which show us the usefulness of the framework from the point of view of governance and management of Green IT in organizations, as well as the consistency and validity of this. So, in this article, with the aim of presenting this multi-case study, we have compiled the most important characteristics about

the methodology, results, and findings we have obtained in this regard.

The rest of the present study is organized as follows: Section 2 contains the background about Green IT, governance and management, and maturity models in this context, as well as the lessons learned we have obtained from the GMGIT 1.0; Section 3 describes the research methodology that we have followed to perform the multi-case study; Section 4 presents the results obtained through the multi-case study; Section 5 discusses the main findings, implications for research and practice, and threats to validity; finally, Section 6 shows the conclusions and proposals for future work.

2. Background

2.1. Green IT

There are many definitions from different authors about Green IT [12,18]; however, we believe that the one that best fits and defines this area, is the following (adapted from [20]): “Green IT is the study and practice of design, build, and use of hardware, software, and information technologies with a positive impact on the environment”.

Starting from this definition, we can see that Green IT is a larger area than many people think, since it not only tries to cover the IT itself, but also aims to contribute to reducing the negative impact that all other areas have. For this reason, we identify two different types of Green IT (following the idea proposed by Erdélyi [21]):

- **Green by IT:** through which it is intended to provide the necessary tools to carry out diverse kind of tasks in different areas in a sustainable manner for the environment (i.e., IT understood as a capacitor or enabler [22]).
- **Green in IT:** through which it is intended to reduce the negative impact that IT has on the environment, due to its energy consumption and the emissions it produces (i.e., IT understood as a producer).

2.2. Governance and Management of Green IT

In organizations, governance and management are the basis on which the different business areas are built [23,24]. It is essential to have an adequate governance and management to attain the objectives and expected results, as well as to obtain business value. On the one hand, the governance establishes the objectives, goals, and vision of the organization, as well as the rules and elements that are necessary to ensure that the expectations of the stakeholders are met. While, on the other hand, through the management all the planning, monitoring, and direction of the different production processes and elements are carried out, with the purpose of achieving the objectives and goals of the organization. That is why it is essential to have an adequate governance and management for each business area, since only in this way the implementation, control, and improvement of the different business areas can be carried out in a correct, efficient, and effective manner.

In the area of IT, the default framework for the governance and management of this area is COBIT 5 (*Control Objectives for Information and related Technology*) [15,25,26,27]. This framework establishes the necessary components (policies, principles and procedures, organizational structures, processes, etc.) to carry out the implementation, control, and audit [46] of different areas of IT (security, risks...), from the point of view of governance and management. However, COBIT 5 does not have any specific adaptation or guidance dedicated to sustainability (an increasingly important area within IT).

That is why, considering this deficiency of COBIT 5 framework, we conducted a Systematic Mapping Study (SMS) [17] to acknowledge the state of the art of the governance and management of Green IT, with special emphasis in the field of audits in this regard.

Through this SMS, the lack of standards, frameworks, and studies in the area of the governance, management, and auditing of Green IT is demonstrated. This can be seen through the results obtained, since of all

the studies found, only two are closely related to this area: in the first study [28] an analysis of the state of the art of the Green IT area is carried out, through which the importance of Green IT audits is highlighted; while in the second study [29] the results of a survey performed to internal auditors from different organizations are shown, in which they are asked about their opinions and experience about Green IT.

Likewise, as gray literature we have found two other relevant studies in this area: the first study [30] analyzes the current state of Green IT in organizations and demonstrates the lack of experience there is in this regard; and the second study [31] identifies the different aspects that auditors should consider when auditing Green IT and demonstrates the lack of standards and frameworks that are specific to Green IT.

Therefore, after having assessed the state of the art and considering all the above, we carried out the development of the first version of the “Governance and Management Framework for Green IT” (GMGIT 1.0) [14]. With the GMGIT we have managed to cover the lack of a framework that helps organizations when implementing, auditing, and improving the Green IT within their business processes. After carrying out different case studies with the GMGIT 1.0, we have refined, improved, and expanded the framework, obtaining a new version more consistent and useful for organizations, the GMGIT 2.0 [16].

In order to give an overview of the GMGIT 2.0, below, we briefly describe how the framework is structured and the different characteristics that can be found in it:

- **Section I.** This section offers an overview of the Green IT area, as well as of the architecture that defines COBIT 5 and how it can be applied/adapted to the specific needs of Green IT.
- **Section II.** This is the section with the greatest weight of the framework, since it defines and establishes the specific enablers for Green IT (based on the enablers established by COBIT 5), specifying in detail for each of them the different characteristics of governance and management of Green IT that should be considered. These enablers are: 1) Principles, policies and frameworks that are specific to Green IT; 2) Processes related to Green IT; 3) Organizational structures that are specific to Green IT; 4) Culture, ethics and behavior that are specific to Green IT; 5) Information that is specific to Green IT; 6) Services, infrastructure and applications that are specific to Green IT; 7) People, skills and competencies that are specific to Green IT.
- **Section III.** This section includes a guide/framework to perform Green IT audits, identifying the phases that must be followed for this, as well as the audit questions (300 questions for *Green by IT* and 300 questions for *Green in IT*) that must be performed to evaluate all the enablers and characteristics established in Section II.
- **Section IV.** This section contains the ISO/IEC 33000-based maturity model, which establishes the different maturity levels of Green IT, the categorization of the processes related to the Green IT in each of these maturity levels, the description of the attributes of each of the processes, and the capability dimension of the processes.

2.3. Maturity Models of Green IT

Maturity models are guides used by organizations to improve the efficiency, effectiveness, operability, etc., of different business areas in an organized and progressive manner [32]. A maturity model contains a set of elements (processes, best practices, analysis criteria, etc.), through which the level of compliance of an organization with respect to certain practices in a specific area of the business is evaluated. Through this evaluation, the gaps and/or weaknesses on which an organization must work to obtain better results and establish a process of continuous improvement are identified. That is why, it is essential that standards and/or frameworks that establish the elements and characteristics to implement, control, and evaluate a certain area of the business, also have a maturity model that allows to carry out all this in an organized and progressive manner. Furthermore, studies have been carried out to

harmonize and map maturity models as evidence of support in this direction [33,34].

Thus, in order to develop a maturity model for the GMGIT, we performed a SMS to know the state of the art of the maturity models in the area of sustainability and of Green IT [35].

Through this SMS, the lack of a consistent and validated maturity model for Green IT is demonstrated. This can be observed through the studies found in the SMS, since only 9 studies of all those analyzed are related to the Green IT area, and of these 9, only 3 are validated [36–38]. However, these 3 outstanding studies (and even the remaining 6) cannot be adapted to the GMGIT, since the elements and the processes structure they deal with are not applicable to the characteristics of the GMGIT.

Therefore, considering the results obtained through the SMS, we decided to carry out the development of a first maturity model for the GMGIT 1.0 [35], based on the ISO/IEC 15504 [39]. Likewise, the case studies carried out with the GMGIT 1.0 (in which the developed maturity model has been used) have also allowed us to improve the maturity model and we have developed an updated version of this model for the GMGIT 2.0 [16], based on the new ISO/IEC 33000 family of standards [40]. Fig. 1 shows a summary of main characteristics of this ISO/IEC 33000-based maturity model developed for the GMGIT 2.0 [16].

2.4. Lessons Learned from the First Version of the “Governance and Management Framework for Green IT”

Through the validations that we conducted with the GMGIT 1.0 [14], we obtained a set of lessons learned that helped us to refine and improve the framework in the second version. These lessons learned must be considered during the validations of the GMGIT 2.0, since we must verify that the errors, inconsistencies or problems that existed with the first version no longer exist and we progress towards an increasingly useful and consistent framework. So, below, we show the four main lessons learned that we identified during the validations of the GMGIT 1.0:

- **Difficulty in the interpretation of concepts.** Through the comments of the managers of the organizations we realized that in certain cases they could not correctly understand and interpret some concepts and definitions of the different enablers of the GMGIT 1.0 (due, mainly, to the novelty and lack of standards of Green IT). Therefore, in the GMGIT 2.0 we have carried out a complete review of all the enablers to explain them in a clearer and more detailed manner.
- **Problems in understanding the activities specific to Green IT.** Another problem in the interpretation, in this case, of the activities specific to Green IT in the process enabler, was based on the fact that the managers of the organizations had many problems understanding and knowing if they actually fulfilled a certain activity. This is because managers were confused and could not distinguish when it was an activity to reduce the negative impact of IT on the environment or when referring to an activity to reduce the negative impact of other business areas in the environment through IT. For this reason, in the GMGIT 2.0 [16] we have carried out a division in this regard, differentiating between activities specific to *Green by IT* and to *Green in IT*.
- **Need for a maturity model.** When we performed the first validations (through case studies) of the GMGIT 1.0, we still did not have a maturity model; we evaluated the 15 processes of the GMGIT 1.0 in full. During these first audits we realized together with the managers of the organizations that we evaluated, that it did not make sense to audit some processes, since they were too complex, and the organizations needed to have well-established other more basic processes before. Therefore, this led us to develop and include in the GMGIT 1.0 a first version of the maturity model based on the ISO/IEC 15504 [35], which we used in the rest of the validations we did with the GMGIT 1.0. However, for the new GMGIT 2.0, we wanted to take a



Fig. 1. Main characteristics of the ISO/IEC 33000-based maturity model developed for the GMGIT 2.0 [16].

step further and update the maturity model to the new ISO/IEC 33000 family of standards [16], which we have used in all the validations performed with this new version of the framework.

- **Need to include more processes.** In the GMGIT 1.0 we wanted to make a first approach, including and adapting to the Green IT only the processes defined by COBIT 5 [15] that we consider most closely related to the Green IT (15 processes in total). We did this in order to first have a proof of concept that was manageable (without becoming an initial framework too complex and intractable), as well as to obtain the necessary experience to continue developing more complex aspects of the framework. However, from the beginning we knew that if the GMGIT 1.0 proved to be a useful guide for organizations, we needed to add more processes to cover all aspects of the business with respect to Green IT. Therefore, in the GMGIT 2.0 [16] we have included 20 new processes to cover this deficiency, and reinforce and expand the scope of the GMGIT.

3. Research Methodology

In order to maintain coherence in the multi-case study, the same characteristics and process of the research methodology have been followed throughout the four case studies, as shown below.

3.1. Multi-Case Study Design

Yin [41] defines case study as “an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”. This type of empirical validation methodology is very suitable especially in new research areas [42], such as Green IT. That is why we have decided to use this type of validation methodology through a multi-case study, following the guidelines defined by [43–45], to perform the validation of the GMGIT 2.0 and of the maturity model.

Therefore, following the guidelines defined for this purpose, first, we have established the research goal of the multi-case study, which is to validate and refine both the GMGIT 2.0 and the ISO/IEC 33000-based maturity model developed for the framework, at the same time that the scope of validations is extended to an international level. To achieve this research goal, we have defined the following research questions, which are based on the lessons learned from the previous validations and the changes we have made in the 2.0 versions:

- **RQ1:** Is the improvement and clarification of the existing processes and the inclusion of the 20 processes consistent and adequate?
- **RQ2:** Is the differentiation between *Green by IT* and *Green in IT* convenient when conducting an audit?
- **RQ3:** Does the updating of the maturity model to the ISO/IEC 33000 family of standards maintain the suitability of all its characteristics?
- **RQ4:** Are the processes (the new ones mainly) at a correct maturity level with respect to the organizational initiatives?
- **RQ5:** Are both the GMGIT and the maturity model applicable in real contexts?

Once all of the above is established, next step is to select the cases (in this context, the organizations) that are adequate and representative to answer the research questions and reach the research goal. For confidentiality reasons, in none of the selected cases is the real name of the organization provided nor specific information that may allow its identification.

On the one hand, we have decided to maintain the parallelism with the type of organizations on which we conducted the validations of the first versions of the framework [14] and of the maturity model [35]. Therefore, three of the four case studies that we have selected have been carried out in IT services centers of different universities: the first, in a Spanish university, identified in this article as SUSC (*Spanish University Services Center*); the second, in a Mexican university, identified in this

article as MUSC (*Mexican University Services Center*); and, the third, in a Colombian university, identified in this article as CUSC (*Colombian University Services Center*).

While, on the other hand, in the fourth organization of this multi-case study, we have decided to introduce a new type of organization, in order to obtain different points of view on the applicability of the GMGIT 2.0 and of the maturity model in another type of organization. For this reason, the fourth case study was carried out in an Italian center dedicated to IT security services, identified in this article as ITSC (*IT Security Center*).

Table 1 shows a summary of the most relevant data of the organizations that have participated in this multi-case study.

The detail of the general information and the Green IT practices carried out by these organizations (as well as the results obtained in each of them), that justify the selection of these as cases, can be observed in Section 4.

3.2. Data Collection

The nature of this type of case studies, based on audits [46], implies a qualitative methodology for data collection, since the techniques used for this are based, mainly, on interviews, observations, and collection of documents.

Thus, following this type of qualitative methodology, the Green IT audits at the four selected organizations were conducted in a period between the end of 2017 and mid of 2018, with an approximate duration between 2 and 3 months per audit. It is important to highlight that these audits were conducted by the authors of this article, who are CISA (*Certified Information Systems Auditor*) by ISACA (*Information Systems Audit and Control Association*) and Chief Auditors of AENOR (*Spanish Association for Standardization and Certification*) for Software Engineering, with extensive experience applying the best practices and audit guides following the ISO/IEC 33000 [40] and the requirements defined in the ISO/IEC 17021 [47]. Likewise, it is also important to highlight that the authors of this article have only conducted the supervision and evaluation through the audits of the application of the GMGIT 2.0 in the organizations. This application of the different processes of the GMGIT 2.0 has been performed by the organizations themselves.

So, during these 4 Green IT audits, the same dynamic was followed in this context of data collection. First, a series of structured interviews with the IT managers and senior management of the different organizations were carried out. At the beginning of this series of interviews, we conducted a first contact and a presentation of the GMGIT 2.0 and of the maturity model, as well as an analysis of the organization itself (mission, vision, main activities, sustainability practices implemented, etc.), which allowed us to establish the scope of the audit.

Through this scope, we determined if a specific audit of *Green by IT*, of *Green in IT*, or both would be conducted (mainly based on the sustainability practices carried out by each organization). We also determined which levels of the maturity model were to be evaluated in detail (although the levels not included were also to be seen in less detail, in order to obtain a feedback in this regard). All this was discussed (aspect by aspect) with the managers of the organizations in another interview, in which those aspects with which they did not agree were modified and,

Table 1
Summary of participant organizations in the multi-case study.

Organization	Country	Type of audit	Period
Spanish University Services Center (SUSC)	Spain	<i>Green in IT</i>	11/2017 – 12/2017
Mexican University Services Center (MUSC)	Mexico	<i>Green in IT</i> & <i>Green by IT</i>	08/2018 – 10/2018
Colombian University Services Center (CUSC)	Colombia	<i>Green in IT</i>	10/2018 – 11/2018
IT Security Center (ITSC)	Italy	<i>Green in IT</i>	05/2018 – 06/2018

once an agreement on the scope was reached, the audit process was initiated. The detail of the different elements of the scope of each of the audits conducted at the selected organizations can be seen in Section 4.

In the audit process, the interviews between the auditors and the IT managers of the different organizations continued. In these interviews we audited in detail and in order (one by one) each of the processes of the maturity levels under evaluation through the Green IT audit questions defined in the GMGIT 2.0 [16], filling out a checklist about the compliance with each practice of the processes. Also, during these interviews we collected the necessary documents and evidences to verify the compliance and detect possible problems and risks in this regard. Likewise, as lessons learned and to reinforce the applicability and validity of our proposal, in the interviews we collected comments from the managers about the different elements and characteristics of the GMGIT 2.0 and of the maturity model.

3.3. Data Analysis and Interpretation

The analysis and interpretation of all the data collected in each case study was performed following the recommendations and guidelines established by COBIT 5 for Assurance [48] and the standard ISO 19011 [49]. Thus, the process was divided into three main phases:

- **Preparation/planning.** As previously mentioned, during the first interview we conducted with each organization, we analyzed the mission, vision, main activities, sustainability practices implemented, and other relevant information about the organization. This general analysis was performed in order to establish the scope and plan of the Green IT audit that was to be conducted. During this first interview, we also made a presentation of the GMGIT 2.0 and of the maturity model to the managers of each organization, and discussed the most relevant characteristics (such as the adequacy of maturity levels and processes at each level) with them.
- **Conducting the audit.** During the audit process, a series of on-site interviews and/or videoconferences were conducted between three CISA certified auditors (who are Green IT governance and management specialists) and the IT managers of the organizations. In these interviews, the analysis of the Green IT practices implemented by each organization was carried out, in order to verify their compliance with the processes of the maturity levels under evaluation. To do this, a checklist with the Green IT audit questions established for each of the processes was filled out, indicating for each question whether it was not applicable or whether it was fulfilled or not (yes, no, and N/A), as well as comments and evidences in this regard. Once this series of interviews was completed, the checklist of all the processes was filled out, and all the documents and evidences were collected, a qualitative analysis of all this information was performed by the three auditors. The results of this analysis were reflected in the audit report, in which, first, the strengths and opportunities for improvement in Green IT are identified in a general manner (as well as the general results and conclusions and an overview of compliance with the maturity levels and processes of Green IT), and, subsequently, the nonconformities and deficiencies found in each of the audited processes are shown in detail, as well as possible solutions to correct them. Thus, the audit report is structured as follows: 1) Audit Information; 2) Auditors Information; 3) Client Information; 4) General Results; 5) Audited Levels and Processes. In this last point, as many sections are included as maturity levels have been considered in the scope of the audit, and, in each of them, each of the audited processes are analyzed in detail.
- **Presentation of the audit report.** Finally, the results of the Green IT audit were presented to the organization. During this presentation, together with each organization, the results both in general and process by process were discussed and analyzed, in order to verify their correctness, and obtain feedback from the members of the

organization about their impressions of the audit conducted and the proposals of the GMGIT 2.0 and the maturity model.

Last but not least, it is important to highlight a final phase of the multi-case study methodology performed after completing the four case studies and focused on analyzing and responding the research questions (cf. Section 5). To carry out this analysis, the authors of this article met and discussed in detail the different results and evidences compiled from the case studies, considering also the feedback obtained from the organizations and the experience and comments of the auditors about their vision on the audits conducted. Based on all this, we performed a qualitative analysis, reaching a consensus and answering together each of the research questions established for this multi-case study.

4. Multi-Case Study Results

4.1. Case Study 1 (Spanish University Services Center – SUSC)

The SUSC is an organization with more than 100 employees that is responsible for managing the IT services of a Spanish university of approximately 30,000 students and 2,000 professors and researchers. This university is very committed to sustainability, carrying out different types of sustainability practices through its Vice-Rectorate of Sustainability. Likewise, SUSC also maintains this commitment and carries out several sustainability practices, including the following initiatives of Green IT:

- Use of virtualization to reduce the number of hardware devices.
- Redesign of the data center to improve cooling and, therefore, energy efficiency.
- Sustainable IT acquisitions; only IT that comply with regulations (EU Energy Star v5, ISO 14001 o ISO 779/9296) and acceptable levels of consumption.
- Recycling and withdrawal of obsolete electronic and electrical material.
- Reduction of the number of printers through a centralized printing service.
- Printing software that identifies and records the printouts of each user of the system and forces users to carry out a double confirmation (one on the originating computer and another on the printing station).
- Automatic shutdown of computers.
- Maintenance of IT by remote control.
- Use of an electric car for travel related to IT maintenance (whenever such displacement is necessary).
- Shared carts with laptops for practical classes.

Once this context was known, during the first interviews that we conducted with the managers of the SUSC, we discussed and established the scope of the audit. First, analyzing the sustainability practices that they carry out in this regard, we established to perform a specific audit of *Green in IT*. This is because the Green IT initiatives that they carry out are aimed at reducing the negative impact that IT has on the environment. On the other hand, we also discussed the processes to be audited and we decided to analyze in detail the processes of the first two maturity levels in detail.

Thus, after conducting the entire audit process, we obtained a series of results that we expressed in the audit report. In this report, first, we identified in a general way both the strengths and the opportunities for improvement that SUSC has in this regard (as can be seen in Table 2).

Likewise, in the audit report we also identified the nonconformities that exist in each of the processes audited, as well as we provided a series of solutions to address these problems.

Table 3 shows by way of example the problems and solutions related to the BAI09 (manage assets) process.

Therefore, after analyzing in detail the results obtained at the audit

Table 2

Strengths and opportunities for improvement regarding Green IT for the SUSC.

Strengths	Opportunities for improvement
<ul style="list-style-type: none"> • High level of commitment and awareness of the members of the board of directors and senior management with sustainability, both by the SUSC and the university. • Large number of Green IT practices implemented: <ul style="list-style-type: none"> ◦ Virtualization. ◦ Improvement of CPD cooling. ◦ Sustainable IT acquisitions. ◦ Recycling of obsolete electronic material. ◦ Reduction of the number of printers through a service of centralized printing. ◦ Printing software that identifies and records the printouts of each user of the system and forces users to carry out a double confirmation. ◦ Automatic turning off of computers. ◦ Maintenance of IT by remote control. ◦ Use of an electric car for travel related to IT maintenance. ◦ Shared carts with laptops for practical classes. 	<ul style="list-style-type: none"> • 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 bases of governance and management of Green IT will be strengthened, which will allow a more effective and efficient implementation of the practices in this regard. • No specific metrics are established to evaluate the correct performance of Green IT practices (beyond the energy consumption metrics). So, it is necessary to implement a greater number of metrics (such as tons of recycled electronic material, amount of water consumed and saved relative to the consumption of printing ink, CO₂ levels, cost and economic savings that the measures implemented imply, etc.) and use them to evaluate periodically and improve the performance of Green IT, which will help achieve greater benefits 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.

Table 3

Problems encountered and possible solutions in the BAI09 (manage assets) process of Level 1 of maturity of *Green in IT* for the SUSC.

Nonconformities encountered	Possible solutions
The assets of <i>Green in IT</i> are not identified, registered and classified according to their criticality.	<ul style="list-style-type: none"> • Identify and record all <i>Green in IT</i> assets, as well as the requirements they cover and the relationships and dependencies between them. • Identify the critical assets of <i>Green in IT</i> and classify them according to the level of criticality that each one has.
There is a software license management system, but the software related and/or affected by the <i>Green in IT</i> is not labeled as such.	<ul style="list-style-type: none"> • Label as “Green” (sustainable) the software related and/or affected by the <i>Green in IT</i>.

of *Green in IT* conducted, we determined that the SUSC is at Level 1 of maturity of *Green in IT* (cf. Section 4.5). However, it is important to highlight that they are doing an excellent work in this regard and they are practically at Level 2 (since the problems of Level 1 are very affordable and easy to solve).

4.2. Case Study 2 (Mexican University Services Center – MUSC)

The MUSC is an organization that provides IT services to a Mexican university of approximately 350,000 students and 40,000 professors and researchers. During the first interview we conducted with the MUSC managers, we could verify the high level of involvement they have with sustainability, both at the organization itself and at the university, due to a specific program for sustainability through which they carry out several sustainability practices. In fact, the MUSC not only carries out

Green in IT practices, but also has Green by IT practices, as shown below:

- *Green in IT* practices:
 - Cloud implementation through Google services.
 - Common and leased printers and photocopiers.
 - Use of recycled paper for printing and photocopying.
 - Special handling for batteries and computer equipment, sending it to a specific unit for treatment.
 - Reuse of hardware from obsolete equipment.
- *Green by IT* practices:
 - Issuance of digital documents and certificates.
 - Registration and presentation of academic thesis and projects electronically.
 - Issuance of digital vouchers for administrative services.
 - Request for administrative services electronically.

So, as the MUSC carries out both *Green in IT* and *Green by IT* practices, we decided to conduct a double audit of *Green in IT* and of *Green by IT*. After discussing it with the managers of the MUSC, within the scope of both audits we also decided to include the processes of the first two maturity levels.

Thus, once both audits were conducted, we obtained a series of results that we included in a single audit report. In this report, first, as general results (uniting both perspectives of *Green in IT* and *Green by IT*) we included the strengths and opportunities for improvement regarding Green IT for the MUSC (as can be seen in the Table 4).

In addition, for each process audited in both audits, we included in the report, separately for *Green in IT* and for *Green by IT*, the non-conformities found and possible solutions. The Table 5 shows an example related to the problems and solutions in the APO10 (manage suppliers) process of the *Green by IT* audit.

Therefore, after analyzing the results obtained, we determined that the MUSC is partially at maturity Level 1, for both *Green in IT* and *Green by IT* (cf. Section 4.5). However, the MUSC is doing very well with respect to sustainability and practically fulfills the first two maturity levels in both perspectives. Once some small details are solved in this first two maturity levels, the MUSC will be surely advance quickly and easily to maturity Level 3.

4.3. Case Study 3 (Colombian University Services Center – CUSC)

The CUSC is an organization belonging to a Colombian university it provides IT services to. This university has approximately 6,000 students and 500 professors and researchers. Currently, the CUSC is working on a project through which they intend to reduce the carbon footprint generated by the consumption of IT in the university. For this reason, they have begun to carry out the following practices:

- Sustainable IT acquisitions (only IT that comply with the regulations and acceptable levels of consumption, through the Energy Star standard).
- Automatic shutdown of computers.
- Configuration of the computers to adjust the brightness level to adequate levels for its use and energy consumption.
- Recommendations for use, 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.

From these sustainability practices, as well as from the objective of the project they have in place, we can see that the CUSC is in the context of the *Green in IT* area, since they aim to reduce the impact of the IT itself. So, we decided to carry out a specific audit of *Green in IT*. Likewise, since they are still in the initial phases of implementation, we also decided to conduct the audit in detail of the processes of the first two maturity levels.

Thus, after carrying out the *Green in IT* audit at the CUSC, we

Table 4
Strengths and opportunities for improvement regarding Green IT for the MUSC.

Strengths	Opportunities for improvement
<ul style="list-style-type: none"> • High level of commitment and awareness of all the members and stakeholders of the MUSC with sustainability and Green IT. • Significant number of sustainability practices implemented: <ul style="list-style-type: none"> ○ <i>Green in IT</i>: <ul style="list-style-type: none"> ■ Cloud implementation through Google services. ■ Common and leased printers and photocopiers. ■ Use of recycled paper for printing and photocopying. ■ Special handling for batteries and computer equipment, sending it to a specific unit for treatment. ■ Reuse of hardware from obsolete equipment. ○ <i>Green by IT</i>: <ul style="list-style-type: none"> ■ Issuance of digital documents and certificates. ■ Registration and delivery of titling work electronically. ■ Issuance of digital vouchers for administrative services. ■ Request for administrative services electronically. • Existence of official documents that endorse sustainability, in which the key aspects of this area are identified (policies, strategies, objectives, etc.). • Existence of a program dedicated to sustainability, which defends sustainability in all areas, provides awareness and training in this area, and from where all aspects related to the environment and Green IT are managed. • Continuous evaluation of performance, effectiveness, costs, etc.; generation of reports of status, results, monitoring, etc.; and high level of corrective actions regarding all aspects that affect or are affected by sustainability. 	<ul style="list-style-type: none"> • The implementation of Green IT practices has been carried out following the organization's own criteria and a series of isolated/independent best practices. So, it is highly advisable to adopt/establish some framework or standard to guide these implementations throughout their life cycle, which will increase the level of success and the improvement of the practices carried out in this regard.

obtained a series of results and we presented the audit report. This report contains, in the first place, the general results of the audit through the strengths and opportunities for improvement in Green IT for the CUSC that we identified (Table 6).

Likewise, the audit report also includes, with respect to process by process, the nonconformities that have been found and possible solutions to these problems. An example of this is shown in the Table 7, through the DSS01 (manage operations) process.

Therefore, after analyzing in detail all the processes of the first two maturity levels and the general results obtained, we determined that the CUSC is partially at Level 1 maturity of *Green in IT* (cf. Section 4.5). Likewise, we want to highlight the involvement and predisposition of the CUSC regarding the environment, thanks to the project that they are carrying out. While it is true that they are in the early stages of implementation, they are doing a good work and they have practically achieved the Level 1 of maturity.

4.4. Case Study 4 (Italian IT Security Center – ITSC)

The ITSC is an Italian organization of approximately 500 employees, dedicated to providing IT security services to different organizations at European level. The ITSC has realized the growing importance of sustainability and Green IT and has decided to start carrying out Green IT practices, such as the following:

Table 5
Problems encountered and possible solutions in the APO10 (manage suppliers) process of Level 2 of maturity of *Green by IT* for the MUSC.

Nonconformities encountered	Possible solutions
<i>Green by IT</i> suppliers are not identified, selected based on the results of the Requests For Information (RFIs) and Requests For Proposals (RFPs), and analyzed/evaluated. Although the organization internally develops <i>Green by IT</i> solutions, resources are needed for these developments (software, specific IT material such as, for example, sensors, etc.). These resources come from an external supplier which must be identified and included in the portfolio of <i>Green by IT</i> suppliers. Likewise, RFIs and RFPs must be established to acquire the adequate resources for the development of <i>Green by IT</i> solutions, and to evaluate the risks and performance of these resources.	<ul style="list-style-type: none"> • Define and establish a portfolio of <i>Green by IT</i> suppliers, categorized by type, relevance and criticality according to the level of risk. • Define and establish Requests For Information (RFIs) and Requests For Proposals (RFPs) for <i>Green by IT</i> suppliers based on the Green IT requirements. • Select <i>Green by IT</i> suppliers based on the results of the evaluation of the RFIs and RFPs. • Agree on the delivery of services with selected <i>Green by IT</i> suppliers through the formal acceptance and signing of contracts between the organization and said suppliers. • Periodically analyze the risks derived from <i>Green by IT</i> suppliers, in order to achieve a delivery of services suited to the needs and capabilities of Green IT. • Periodically evaluate the compliance and performance of <i>Green by IT</i> suppliers regarding the delivery of agreed services.

- Awareness program for employees to use digital material in order to reduce the use of paper printing documents (which impacts on lower energy consumption and reduction of printing devices, as well as less consumption of ink and paper).
- Awareness program for employees for the efficient use of IT in order to reduce energy consumption in this area.

Currently, the ITSC is in the very early stages of implementing Green IT practices, but has wanted to participate in this study in order to carry out an implementation from the beginning following a framework such as the GMGIT in a progressive and organized manner. In order to identify the starting point, we decided to carry out an audit of *Green in IT* (due to the nature of the practices that ITSC carries out and plans to carry out in the future), as well as to audit the processes of the first two maturity levels in detail.

Thus, after carrying out the *Green in IT* audit at the ITSC (considering the processes of the first two maturity levels), we developed the audit report with the results obtained. As in the rest of the studies, in this report we first identified the general results through the strengths and opportunities for improvement regarding Green IT for the ITSC (Table 8).

Likewise, in the audit report we also identified the nonconformities found and possible solutions for each of the audited processes, as shown in the example of the Table 9 through the BAI09 (manage assets) process.

Therefore, analyzing all these audit results, we determined that the ITSC is at level 0 of maturity of *Green in IT*, since it does not comply with the basic practices of Level 1 (cf. Section 4.5). However, this result is normal, since the ITSC is in the process of initiation in this field of Green IT. They have chosen the right path and their involvement with sustainability and Green IT is growing, so we expect an adequate progress in this regard for ITSC. The study has however represented an important beginning for formally introducing several practices and “ways of doing” into the organization.

4.5. Compliance with the Audited Processes of Green IT

Table 10 shows the compliance of each organization that have participated in this multi-case study regarding the audited processes of

Table 6
Strengths and opportunities for improvement regarding Green IT for the CUSC.

Strengths	Opportunities for improvement
<ul style="list-style-type: none"> • Existence of a sustainability 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: <ul style="list-style-type: none"> ◦ Sustainable IT acquisitions (only IT that comply with the regulations and acceptable levels of consumption, through the Energy Star standard). ◦ Automatic shutdown of computers. ◦ Configuration of the computers to adjust the brightness level to adequate levels for its use and energy consumption. ◦ Recommendations for use, 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 computing equipment supposes, which strengthens and helps the implementation, evaluation and improvement of the sustainability practices that are carried out, as well as those possible future practices. 	<ul style="list-style-type: none"> • 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 computer 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.

Table 7
Problems encountered and possible solutions in the DSS01 (manage operations) process of Level 1 of maturity of *Green in IT* for the CUSC.

Nonconformities encountered	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.	<ul style="list-style-type: none"> • 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 <i>Green in IT</i> in the management of the environment and in the management of the facilities are not considered.	<ul style="list-style-type: none"> • Ensure that the management of the environment considers and complies with the requirements of <i>Green in IT</i>. • Ensure that the management of the facilities considers and complies with the requirements of <i>Green in IT</i>.

Green IT of the first two maturity levels.

By way of illustration, if an organization complies with all the activities and practices of a process (defined in GMGIT 2.0 [16]), it is determined that the organization has “full compliance” with that process. While, if an organization does not comply with the activities and practices of a process (that is, if any nonconformity has been found), two

Table 8
Strengths and opportunities for improvement regarding Green IT for the ITSC.

Strengths	Opportunities for improvement
<ul style="list-style-type: none"> • Growing and strong level of commitment and awareness of the members of the management with sustainability. • Start of implementation of Green IT practices: <ul style="list-style-type: none"> ◦ Awareness program for employees to use digital material in order to reduce the use of paper printing documents (which impacts on lower energy consumption and reduction of printing devices, as well as less consumption of ink and paper). ◦ Awareness program for employees for the efficient use of IT in order to reduce energy consumption in this area. 	<ul style="list-style-type: none"> • Absence of official documents regarding the policies, strategies, objectives and other enablers of Green IT. So, it is necessary to formalize these aspects, through which the bases of governance and management of Green IT will be strengthened, which will allow a more effective and efficient implementation of the practices in this regard. • No specific metrics are established to evaluate the correct performance of Green IT practices. So, it is necessary to implement metrics in this regard (such as the amount of water consumed and saved in relation to the consumption of printing ink, CO₂ levels, cost and economic savings implied by the measures implemented, etc.) and use them to evaluate periodically and improve the performance of the Green IT, which will help achieve greater benefits in this regard. • The implementation of Green IT practices has been carried out and is being carried out according to the organization’s own criteria. So, it is highly recommended to adopt some framework or standard to guide these implementations throughout their life cycle, which will increase the level of success and improvement of the practices carried out in this regard. • Small number of implemented Green IT practices, due to the early phases of implementation in this field. So, it is recommended, among others, to carry out initial practices such as: <ul style="list-style-type: none"> ◦ Sustainable IT acquisitions (only IT that comply with acceptable levels of consumption and internationally recognized sustainability standards, such as EU Energy Star v5, ISO 14001 or ISO 779/9296). ◦ Implementation of a service for the removal and subsequent recycling of electrical and electronic waste, that is, all obsolete IT equipment.

things can happen: 1) If it complies with some practices while others do not, it is a “partial compliance” with that process; 2) If it not complies with any practice at all, it is a “non-compliance” with that process.

5. Discussion

5.1. Main Findings

As mentioned above, the research goal of this multi-case study is “to validate and refine both the GMGIT 2.0 and the ISO/IEC 33000-based maturity model developed for the framework, at the same time that the scope of validations is extended to an international level”. Thus, after analyzing the results and feedback obtained in the four case studies that have been conducted, we have reached a series of main findings from different points of view:

GMGIT 2.0 and ISO/IEC 33000-based maturity model. In this regard, we have strengthened the validity and applicability of both versions when implementing, auditing, and improving the Green IT in organizations. During the four case studies that we have conducted, we have been able to observe that the new changes, as well as the existing components and other characteristics, maintain the coherence and are

Table 9
Problems encountered and possible solutions in the BAI09 (manage assets) process of Level 1 of maturity of Green in IT for the ITSC.

Nonconformities encountered	Possible solutions
The assets of <i>Green in IT</i> are not identified, registered and classified according to their criticality.	<ul style="list-style-type: none"> • Identify and register all the assets of <i>Green in IT</i>, as well as the requirements that they cover and the relationships and dependencies between them. • Identify the critical assets of <i>Green in IT</i> and classify these according to the level of criticality that each one has.
The life cycle of <i>Green in IT</i> assets is not managed.	<ul style="list-style-type: none"> • Ensure that the requirements and guidelines for the use of the assets of <i>Green in IT</i> are satisfied throughout their whole life cycle, in order to maintain the efficiency, effectiveness and reliability of these assets.
The cost of <i>Green in IT</i> assets is not evaluated and optimized.	<ul style="list-style-type: none"> • Evaluate the costs of the assets of <i>Green in IT</i>, to optimize these and adapt them to the needs of Green IT and of the organization.
There is no license management system for software related to/affected by <i>Green in IT</i> (software labeled as “green”).	<ul style="list-style-type: none"> • Establish a license management system for the software related to/affected by <i>Green in IT</i>, in an effort to ensure that this software keep on functioning properly and that the requirements of Green IT are supported.

Table 10
Compliance of the participant organizations with the audited processes of Green IT.

Audited processes	SUCS <i>Green in IT</i>	MUSC <i>Green in IT</i>	<i>Green by IT</i>	CUSC <i>Green in IT</i>	ITSC <i>Green in IT</i>
Maturity Level 1					
BAI09. Manage assets	P	P	P	F	N
DSS01. Manage operations	F	F	F	P	N
Maturity Level 2					
APO01. Manage the IT management framework	P	P	P	N	P
APO02. Manage strategy	P	P	P	N	P
APO06. Manage budget and costs	P	F	P	N	N
APO08. Manage relationships	N	F	F	N	N
APO10. Manage suppliers	P	F	N	N	N
BAI01. Manage programs and projects	N	P	P	N	N
BAI02. Manage requirements definition	N	P	P	N	P
BAI03. Manage solutions identification and build	P	F	F	N	N

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

adequate. In the same way, organizations have seen these components reflected in the practices they carry out and have discovered different characteristics that they had not considered and recognize that are necessary.

- **Organizations audited.** We have realized that organizations are still disoriented on issues related to Green IT, mainly due to the lack of reliable standards/frameworks in this regard. While it is true that more and more organizations realize the importance of Green IT and carry out initiatives such as getting involved in the development and validation of frameworks such as the GMGIT, they still have a lot of work to do about it. In relation to the organizations of the present multi-case study, we have encountered both extremes. On the one hand, we have audited an organization (ITSC) that is just beginning

to implement Green IT and is looking for a guide that helps carry out this process, given the organization currently has no background on the topic. On the other hand, we have had two organizations (SUSC and CUSC) that have been involved in these issues of Green IT for a while, doing a series of practices according to their own criteria and following a good path, but they still do not obtain the results they expect. And, finally, we have found an organization (MUSC) very involved with the Green IT, which carries out a large number of practices of different kinds in this regard, and which is obtaining very good results. However, the same thing happens to the four audited organizations, regardless of whether they are better or worse in Green IT: they demand standards/frameworks that help them to follow a guide to implement, control, and improve the practices of Green IT in a progressive and systematic manner. And that is why they have been involved in this multi-case study.

- **Green IT and sustainability.** We continue reinforcing the theory that Green IT and sustainability are increasingly important and indispensable both for organizations and for society as a whole. The organizations have told us that everything related to the area of sustainability has become one of the main assets of the business. For its part, the Green IT is one of the most relevant fields in this regard, due to the impact that IT has nowadays, and will be vital in the near future to stay in the business.

Regarding the lessons learned that we have obtained through the results and feedback from the four case studies conducted, we have identified the need to adapt/apply international standards in the GMGIT. This is because the application of standards, such as the ISO 14000 series [50], will consolidate the practices and components defined in the GMGIT, making it a more consistent and valid framework. In the same way, this application of international standards has a lot of value for organizations, since they not only ensure that they follow a framework supported by wide adopted standards, but it also helps them to obtain valuable certifications in this regard.

In the following subsections, the exploratory research questions established for this multi-case study are analyzed in detail, answering them based on the results and findings obtained.

5.1.1. RQ1: Is the improvement and clarification of the existing processes and the inclusion of the 20 processes consistent and adequate?

During the audits we have conducted at the four organizations, we have observed that the improvement and clarification in the definition of different characteristics, concepts, and processes has helped organizations to have fewer doubts and better understand these aspects, as well as what is being evaluated. From our point of view as auditors, our work has also improved, since it has allowed us to focus more on the audit itself than on explaining and understanding the different aspects under evaluation.

Furthermore, the inclusion of 20 new processes maintains the consistency with respect to the rest of existing processes and components, since it follows the same logic and we have checked in practice that the relationship between all the processes is adequate. Likewise, we have also been able to observe that, thanks to these new 20 processes, the framework and the whole audit process have been reinforced, since necessary features that were missing in the previous version have been included.

Therefore, to answer this research question, we have considered the evidence based on the experiences of the auditors themselves, comparing the audits conducted with the GMGIT 1.0 with those of the GMGIT 2.0. So, as an example of this comparison, when organizations read the descriptions and other aspects of the different GMGIT 1.0 processes, they always asked the auditors for many of these aspects since they could not understand them due to lack of detail, clarity, and ambiguity. This was a problem for the auditors, because they had to explain many concepts and could not focus adequately on the audit. With the changes made in the GMGIT 2.0 in this regard, this problem has been

greatly reduced. Although there are always aspects that the auditors have to explain (in this case, mainly, because of the novelty of the Green IT area), the auditors estimate that the time devoted to these explanations has been reduced by around 70%. The organizations understand in a simpler and faster manner the processes under evaluation. In addition, the inclusion of the 20 new processes has also helped in this regard, covering the gaps in the processes that existed due to the lack of other more specific processes (especially, regarding inputs and outputs, activities, and practices).

5.1.2. RQ2: Is the differentiation between Green by IT and Green in IT convenient when conducting an audit?

The audited organizations have pointed out that this differentiation between *Green by IT* and *Green in IT* is very wise. For them it is much easier and more convenient to have these two perspectives because in this way they understand the scope much better and they can focus more specifically on the implementation and evaluation/audit of those practices that they consider most appropriate.

Likewise, as auditors, the audit process has been greatly improved and simplified, since it has allowed us to be more specific and direct in explaining, identifying, and analyzing all the processes and elements under evaluation.

Comparing the evidence and experience obtained, with the GMGIT 1.0, the organizations did not understand/define their scope clearly and took a long time to correctly identify all the Green IT practices they carried out. In fact, organizations overlooked practices related to Green IT because they were constantly disorienting themselves. One of the main misunderstandings was that they thought that those practices in which they used IT to reduce consumption in other areas were not within the audit scope, when with the GMGIT 1.0 all types of Green IT practices were covered. Organizations only considered those practices that were directly related to sustainability in IT and auditors often detected practices that had not been discussed before and whose aspects of governance and management should have been considered in processes already audited, which meant re-evaluate these aspects. Now, with the GMGIT 2.0 organizations no longer have this problem, because the scope is much more specific and detailed. The audited organizations in this multi-case study understood from the planning stage the different types of Green IT practices that may exist and identified without problems those practices that were to be included in the scope of the audit. During the audit phase, the organizations were not disoriented from the scope at any time, it was clear what was being evaluated. All this translated into a more direct audit process, making better use of time, and getting higher quality answers, since the different activities for which the auditors asked were better understood.

5.1.3. RQ3: Does the updating of the maturity model to the ISO/IEC 33000 family of standards maintain the suitability of all its characteristics?

The update of the maturity model from the ISO/IEC 15504 [39] to the new ISO/IEC 33000 [40] has not been a problem and the suitability is maintained, since the basis of both standards is the same. Both the maturity levels and the attributes of the processes are maintained. The only changes that have taken place are the inclusion of the 20 new processes added to the GMGIT and small modifications in some concepts to adapt them to the new standard (concepts that have been updated in the ISO/IEC 33000 to make it more open and with a wider application range than its predecessor) [16].

Thus, when we have applied this new ISO/IEC 33000-based maturity model in the four case studies we have conducted, we have not had any problems, everything in the audit process related to the maturity model has been conducted normally, and we have been able to verify the adequacy and consistency with the previous model.

5.1.4. RQ4: Are the processes (the new ones mainly) at a correct maturity level with respect to the organizational initiatives?

Before carrying out the audit, in each of the four audited

organizations we have analyzed all the processes included in the five maturity levels together with them. From these analyzes we have obtained feedback that has helped us to verify that our proposal is accurate. It is important to highlight that these analyzes were based on two main questions: 1) Do you consider appropriate maturity levels established? 2) Do you consider that each of the processes is at the appropriate maturity level?

Likewise, during the audit, we have strengthened the proposal of the processes included in the first maturity levels. We have been able to corroborate that the organizations begin to carry out actions in these base processes of the first two maturity levels, before having a solid implementation and develop in detail the more specific processes that are found from Level 3 of maturity. In fact, while we audited the different aspects of the processes of the first two maturity levels, we also referenced aspects of processes of higher levels that, in a certain manner, were related to what was being audited, although, of course, it meant a step forward or a more advanced development. In these small analyzes, organizations told us that, either it is something they have not considered yet because they are not so advanced in this regard, or it is one of the lines of future work that they have in mind to develop. This evidences in a more practical manner that the processes are at the appropriate maturity levels.

5.1.5. RQ5: Are both the GMGIT and the maturity model applicable in real contexts?

The results obtained in the four case studies conducted, the main findings identified, and the analysis of the different research questions show that both proposals of the GMGIT and the maturity model are applicable in real contexts. In the same way, the audited organizations have been very satisfied with the expectations they had about each case study and they have given us a very positive feedback about the usefulness of the GMGIT as a guide to progressively and systematically implement, audit, and improve the practices that they carry out (or intend to carry out) with respect to Green IT. In fact, this usefulness and applicability both the GMGIT and the maturity model is also evidenced through the improvement plans that we are carrying out with the audited organizations (following the guidelines established by the ISO/IEC TR 33014 standard [51]), since they want to continue adopting our proposals to advance and improve in the area of Green IT.

5.2. Implications for Research and Practice

The results and findings obtained in this multi-case study have a high transcendence for research. Thanks to the validations made with the GMGIT 2.0 and the ISO/IEC 33000-based maturity model for the framework, researchers within the area of sustainability, Green IT, and IT, have a basis on which to carry out new innovative research. Because the scope of the GMGIT is very generic since it deals with high-level issues related to governance and management, researchers in this area can develop in-depth research on different governance, management, and/or auditing characteristics of Green IT. Likewise, they can conduct new research with the GMGIT in different contexts in which it has not yet been proven, such as, for example, applying it in organizations in the aeronautical sector.

On the other hand, practice is also greatly benefited from these validations and results obtained. Thanks to the consistency, applicability, and usefulness of the GMGIT 2.0 and the ISO/IEC 33000-based maturity model for the framework, the organizations and practitioners finally have a valid guide to help them carry out the definition, implementation, control, audit, and improvement of the Green IT, all in a gradual and systematic manner. This will lead to more and more organizations deciding to carry out sustainability practices in and by IT, and will allow IT auditors and managers to extend their competencies to this area of Green IT.

5.3. Threats to Validity

In the following subsections, the threats to validity that exist in the present multi-case study are analyzed in detail, based on the four aspects of validity defined by [43,44].

5.3.1. Construct Validity

First, regarding this kind of validity, it must be considered that the two proposals evaluated (the GMGIT and the maturity model) have been developed following two well-known and wide adopted standards. On the one hand, the GMGIT has adopted the enablers structure established by the COBIT 5 framework [15], following and adapting the basic concepts of governance and management that it defines. And, on the other hand, the maturity model has been based on the ISO/IEC 33000 [40], following and adapting the maturity levels, attributes of the processes and other applicable and relevant characteristics.

Therefore, thanks to following these standards, discrepancies that could arise between researchers and practitioners have been avoided. However, what must be considered is that the concepts, definitions, and other characteristics of Green IT included in both proposals may not be interpreted in the same way by researchers and practitioners, posing a threat to validity. That is why, in order to mitigate this threat, we have tried to pay special attention and emphasize the definition and explanation of these aspects of Green IT. This can be seen in the differentiation that we have performed between *Green by IT* and *Green in IT*, in order to clarify and avoid confusion when interpreting these concepts and the different activities of the processes.

5.3.2. Internal Validity

The threats that can affect the internal validity in this type of case studies (based on audits) are related to the problems that the organizations can have to carry out the process of audit and implementation/improvement of the Green IT following the proposed maturity model. For example, these problems can be the lack of commitment to the topic to be addressed by senior management and IT managers, lack of resources and/or time, internal discrepancies, etc.

Therefore, to mitigate this threat, during the first interviews we conducted with the senior management and IT managers, we carried out a presentation of the proposal of the GMGIT and of the maturity model in order to eliminate the discrepancies and doubts that existed in this regard, as well as to obtain the commitment of the organizations. Likewise, the initial information we obtained to establish the scope of the audit was also used to analyze whether the organizations had the resources and time necessary to carry out this process of audit and later implementation/improvement.

5.3.3. External Validity

Regarding threats to external validity, in this case, they are related to the type of organization that has been chosen to carry out the case studies. All four are organizations that are dedicated exclusively to the IT area, providing and managing IT services. Thus, the business model on which the multi-case study has been conducted is very similar, so there may be discrepancies with respect to other business models that have not been considered.

Therefore, to mitigate this threat, since the case studies were going to be carried out in the same type of organization to maintain a consistency in first instance, we decided to carry out this empirical validation at international level. The different contexts of the organizations (culture, way of working, applicable regulations, etc.) allowed us to mitigate this threat in a certain way and to generalize the proposals of the GMGIT and of the maturity model thanks to the differences that we find among these organizations. Likewise, as future work we intend to carry out more case studies in organizations of different sectors, such as, for example, the aeronautical or the automotive sector. In this way, we will be able to mitigate this threat completely.

5.3.4. Reliability

In this type of validity, the threats that exist are related to the analysis and interpretation of the data obtained in each of the case studies. The main disadvantage of this kind of case studies based on audits is that the analysis and interpretation of the data and results is too abstract, with a qualitative basis (without quantitative data that allow analyzing and deducing in greater detail the improvements and benefits obtained), and based on the knowledge, impressions and experience of the auditors.

Therefore, to mitigate these threats, the data collected (through interviews, observations, and collection of documents) have been analyzed and interpreted independently by each of the authors; so the bias among each other has been reduced. Likewise, in order to reach general and unique findings and results (both in the audits and in the multi-case study), the analyzes of each of the authors were pooled and analyzed point by point to identify aspects not considered by some of the authors, as well as treating possible discrepancies between results. The few discrepancies found were only due to the omission (by one of the authors) of any of the data collected, so after resorting and presenting these data, a general consensus was reached and the discrepancies were resolved.

However, it is important to highlight that the authors belong to similar groups that collaborate closely, so threats still exist. So, in order to completely mitigate these threats, in the future detailed documentation will be prepared so that external researchers and other practitioners can use and validate the GMGIT and the maturity model, obtaining their own results and conclusions in this regard.

6. Conclusions and Future Work

More and more organizations around the world realize that the future and true growth lies in being environmentally responsible. The enormous potential and impact of sustainability in areas as relevant to the business as IT [52] is leading organizations to implement the so-called Green IT practices. Thanks to this type of practices, organizations are obtaining multiple benefits such as, for example, improvement of the efficiency and effectiveness of business processes, risk reduction, better reputation, among others [3]. However, organizations lack standards or frameworks that help them to carry out this type of specific Green IT practices.

For this reason, we developed the first version of the “*Governance and Management Framework for Green IT*” (GMGIT 1.0) [14], through which we establish all the characteristics and components that organizations must consider when implement the Green IT, from the governance and management of this area. After performing a series of validations with the GMGIT 1.0, we refined and improved it obtaining a second version, the GMGIT 2.0 [16]. Following the same logic as with the first version, in order to validate and continue improving the GMGIT 2.0, we have conducted a series of empirical validations through case studies in four organizations at international level, whose characteristics and main results have been presented in this article.

The results obtained through this multi-case study presented and the discussion of them demonstrate the applicability, usefulness, and consistency of the GMGIT 2.0 when carrying out the implementation, audit, and improvement of Green IT. Also, thanks to this new version of the framework we have managed to solve the problems encountered during the validations conducted with the GMGIT 1.0.

On the other hand, it is important to highlight that the audited organizations have been very satisfied with each case study, since thanks to it they have been able to know what their current status is in Green IT to start organizing and carrying out all the implementation work of new Green IT practices and improvement of existing ones following the GMGIT 2.0. In fact, we are working with these organizations through improvement plans (following the ISO/IEC TR 33014 standard [51]), through which promising results are being obtained and organizations are improving their efficiency and effectiveness with respect to Green IT

and sustainability in general.

Likewise, we are not only conducting improvement plans in these organizations to continue validating, refining, and improving the GMGIT 2.0, but we are also obtaining lessons learned and feedback from these case studies and improvement plans for future lines of work that will allow us to transfer knowledge to interested companies [53] and plan for families of experiments [54]. Thus, we are working on adapting and integrating wide adopted international standards related to sustainability, such as the ISO 14000 family of standards [50], in which we have already obtained a first results [55]. On the other hand, as future work we also have in mind to expand the scope of the GMGIT towards social and economic sustainability, since until now we have only considered environmental sustainability.

To save the environment begins with us and it is our responsibility to act and help the rest of society and organizations act against these terrible damages to preserve the planet that we will leave to future generations.

CRedit authorship contribution statement

J. David Patón-Romero: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Maria Teresa Baldassarre:** Conceptualization, Validation, Formal analysis, Investigation, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Moisés Rodríguez:** Conceptualization, Validation, Formal analysis, Investigation, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Per Runeson:** Conceptualization, Methodology, Validation, Resources, Writing - review & editing. **Martin Höst:** Conceptualization, Methodology, Validation, Resources, Writing - review & editing. **Mario Piattini:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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