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Green IT Governance and Management based on ISO/IEC 15504

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ABSTRACT

Organizations around the world are increasingly concerned about the environment, adopting sustainable practices in their business processes. In the field of Information Technologies (IT) several Green IT practices have been proposed, but in isolation, so a framework is needed if the Green IT is to be implemented and improved in an efficient and integrated way. In this paper, we propose a maturity model (based on ISO/IEC 15504) to help organizations implement the governance and management of Green IT gradually, as well as to improve their maturity level in this area. The validation of this proposal by experts and a case study seems to indicate that the proposal can be useful for implementing and improving the Green IT processes in organizations.

1. Introduction

In recent years, Information Technology (IT) has become one of the pillars of our society, changing not only the way we relate to each other and the way companies do business, but also how we interact with the planet. However, in this interaction with the planet we have lost our commitment to the environment, our commitment to life. Therefore, in our society a strong ecological awareness has emerged in order to address this problem, with the aim of obtaining a healthy planet and a sustainable ecosystem.

That is why the concept of Green IT has emerged in the area of IT, which seeks to bring the idea of environmental sustainability [1] closer to IT. Green IT can be defined as "*the study and practice of design, build and use of hardware, software and information technologies with a positive impact on the environment*" (definition adapted from [2]).

The importance of the idea of sustainability in our society and the growing demand of "green" products has made Green IT a determining area, gaining increasing importance within organizations, since it has become an important asset to add value to business [3,4].

However, while there is a growing number of research papers [5] and isolated best practices of Green IT, there are still no specific standards to help organizations establish the bases of these best practices (the governance and management of Green IT) and verify that these Green IT implementations are sufficient, correct and work as expected [6].

That is why we have developed a first version of the "Governance and Management Framework for Green IT" [7], in which we have established the necessary characteristics to define, implement and audit the governance and management of Green IT in an organization. This developed framework however lacks a maturity model through which the characteristics of governance and management of Green IT established in this framework can be gradually evaluated and implemented.

Thus, in this article we propose a maturity model based on ISO/IEC 15504 (a process reference model) for the governance and management of Green IT, i.e., a ISO/IEC 15504-based maturity model for the "Governance and Management Framework for Green IT".

The development of this ISO/IEC 15504-based maturity model for the "Governance and Management Framework for Green IT" is highly relevant for practitioners in the fields of the maturity models, sustainability and Green IT. On the one hand, auditors and IT managers, mainly, will be able to expand their operating range to this new field of Green IT, achieving more specific and comprehensive audits and consolidating the best practices of Green IT in the organization. Furthermore, on the other hand, organizations will be able to carry out best practices of Green IT and, together with those that already carry them out, they will obtain great benefits in this area, since will they not only have a base on which to start working and a roadmap, but they will also be able to evaluate their situation and gradually and systematically improve in this area easily and straightforwardly.

The rest of this paper is organized as follows: Section 2 explains the related work about the existing maturity models that are related to the subject of study (ISO/IEC 15504, IT, Green and Green IT); Section 3

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shows a systematic mapping study carried out in the area of the maturity models of sustainability, and of Green IT in particular; Section 4 presents the proposal of the ISO/IEC 15504-based maturity model for the "Governance and Management Framework for Green IT"; Section 5 shows the validations carried out for the process reference model proposed; and, finally, Section 6 presents the conclusions and future work to be done in this area. Also, Appendix A includes the primary studies selected in the systematic mapping study carried out in Section 3, and Appendix B shows the definitions and purposes of the processes of the "Governance and Management Framework for Green IT" organized according to the proposed ISO/IEC 15504 maturity levels.

2. Related work

In the following sub-sections, the different maturity models based on ISO/IEC 15504 and related to the area of IT, sustainability (Green) and Green IT are analyzed.

2.1. ISO/IEC 15504-based maturity models

The ISO/IEC 15504 [8], also known as Software Process Improvement Capability Determination (SPICE), is a set of standards, developed by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), that propose models for improving and assessing processes related to information systems and software products.

ISO/IEC 15504 has been applied in many fields such as aerospace [9], software engineering [10], government [11], risk management [12], automotive [13,14], information security [15], health [16,17], nuclear energy [18], among others. However, so far there is no application of this standard in the field of Green IT.

It is also important to note that a few years ago (in 2012 at the ISO/IEC JTC 1/SC 7 plenary meeting in Jeju, South Korea) a proposal for defining an extension to the ISO/IEC 15504 to embrace sustainability was presented and accepted but failed to obtain enough resources to be carried on. It was a shame because we believe that the community has missed an opportunity to advance in this area.

Based on the ISO/IEC 15504, we developed a maturity model of software engineering [10] in 2008, used by AENOR (*Asociación Española de Normalización y Certificación*). Furthermore, another important contribution has consisted in developing support tools for harmonizing multiple reference models that take into account similarities among existing models [19,20] when adopting new ones within an organization. To this end, there is evidence on application to various contexts [21].

On the other hand, the new family of standards ISO/IEC 33000 [22], developed by ISO and IEC, is replacing ISO/IEC 15504, reorganizing and extending the latter for the evaluation and improvement of the capacity and maturity of an organization's processes. Based on this family of standards, we developed a model for data quality processes implantation [23].

2.2. Other IT maturity models

In relation to the other maturity models related to the area of IT, the most ingrained and widely-used today by organizations are outlined below:

- Capability Maturity Model Integration (CMMI) [24]: this model, originally developed by Carnegie Mellon University (CMU) and administered nowadays by the CMMI Institute (acquired recently by ISACA – *Information Systems Audit and Control Association*), aims to evaluate and improve the processes of an organization for the development, maintenance and operation of information systems and software products.
- Maximizing the Combined Effects of COBIT 5 and CMMI [25]: this proposal is being developed by ISACA, in order to adapt the CMMI model to COBIT 5 (*Control Objectives for Information and related Technology*) [26], identifying at which maturity levels of the CMMI model must the different COBIT 5 processes of governance and management of IT be included.

2.3. Green and Green IT maturity models

In relation to the sustainability and Green IT maturity models, Section 3 shows in detail a systematic mapping study that we have carried out in this area.

Of the 27 studies found in this systematic mapping study, only 3 are the most complete and related to the Green IT maturity models (Buchalcevova [S02], Curley et al. [S04], and Hankel et al. [S09]). However, these studies are adapted and deal with a specific problem, which makes it impossible to adapt them to the "Governance and Management Framework for Green IT" that we have developed (model that is more general within the area of governance and management of Green IT).

Therefore, the results obtained through this systematic mapping study demonstrate the novelty of the area and the lack of a solid Green IT maturity model and, consequently, the need to elaborate and validate a model of this type.

3. Green and Green IT maturity models – a systematic mapping study

In this section, a systematic mapping study is carried out in relation to the sustainability maturity models that currently exist, placing special emphasis on the area of Green IT.

3.1. Research protocol

A systematic mapping study (SMS, hereinafter) he is a method for investigating about a specific area, in order to collect and categorize all the information that exists on it.

There are different guidelines for carrying out a SMS. In particular, the execution of the present SMS was based on work such as Budgen et al. [27], Kitchenham [28], and Petersen et al. [29].

In conducting this SMS, three main stages have been carried out: Planning, Execution and Documentation. The first two stages are described in the following sub-sections of the current section, and the documentation stage corresponds to section of results.

It is also important to note that this SMS began in February 2017 and was completed in May 2017.

3.1.1. Planning stage

In the following subsections, the characteristics of the activities carried out in this planning stage are detailed.

3.1.1.1. Research questions. This SMS aims to examine the state of the art of publications in the field of maturity models of sustainability, and of Green IT in particular, in order to identify existing gaps and propose new areas of research. To that end, the research questions defined in Table 1 have been established.

3.1.1.2. Search strategy. To carry out the automated search of studies, we referred to the *Scopus* database, with search strings as shown in Table 2. We have selected this unique database as it includes all of the primary venues, either journals, conferences or workshops, that concern topics relevant to the search strings. As can be seen, this search string is divided into two parts which represent, on the one hand, the area of sustainability, and on the other hand, the scope of maturity models.

The search was applied to the title, abstract and keywords of the studies, and the studies between the years 2006 and 2016 (inclusive)

Table 1
Research questions.

Research Questions	Motivation
RQ1. What proposals exist on sustainability maturity models?	Determine the number of current publications and the trend over recent years in relation to sustainability maturity models.
RQ2. What empirical evidence exists on sustainability maturity models?	Determine what type of empirical method has been used for the validation of the proposed maturity model(s).
RQ3. What standards, frameworks, or models are followed to measure the maturity of Green IT?	Determine what standards, frameworks, or models are used to assess the maturity of Green IT.

Table 2
Search string.

Concept	Alternative Terms & Synonyms	
Sustainability	(Green OR Sustainability)	AND
Maturity models	"Maturity Model"	

were considered. This last restriction is due to the fact that the field of sustainability, and especially of Green IT, is relatively young and it has only been over the last decade that these ideas have been developed most.

3.1.1.3. Selection criteria of primary studies. The studies compiled in the automated search were evaluated according to their title, abstract and keywords, in order to determine whether or not they would be included among the potential studies that would be analyzed in more detail later to select the primary studies.

First of all, studies that met at least one of the following inclusion criteria were considered:

- I1: studies in English that refer to maturity models in the area of sustainability.
- I2: complete studies published between 2006 and 2016 in books, journals, conferences, or prestigious workshops with peer review.
- In addition, studies that met any of the following exclusion criteria would not be included:
- E1: articles for discussion or opinion, or which were available only in the form of abstracts or presentations.
- E2: duplicate or similar studies (the most complete and recent study was the one taken into consideration).
- E3: studies whose main contribution is not related to sustainability maturity models, or in which this subject is considered superficially.

Other than automated search on the Scopus database we also conducted snowballing [30]. That is, studies from the references included in each of the chosen studies were to be evaluated in the same way.

3.1.1.4. Quality assessment criteria. An important aspect for obtaining better results and future research is to measure the quality of the studies, so as to determine what the most representative and relevant studies in the area in question are, especially when discussing the results obtained and analyzing in detail the most outstanding studies (see Section 3.3). To do this, a three-point scoring system (−1, 0 and +1) was established, which was to be applied to each of the following issues (obtaining a total value between −5 and +5):

a. The study contains a clear and detailed description (with appropriate and sufficient justifications) on the characteristics and the application of sustainability maturity models. Possible answers are: "Yes" (+1), "Partially" (0), and "No" (−1).
b. The study presents a clear and detailed guide (with appropriate and sufficient justifications) on how to measure maturity in the sustainability area. Possible answers are: "Yes" (+1), "Partially" (0), and "No" (−1).
c. The study validates the idea about the sustainability maturity model that it defends. Possible answers are: "Empirically validated through a case study, survey, or experiment" (+1), "Applied through a test of concepts" (0), and "Not validated" (−1).
d. The study has been published in a relevant journal or conference (considering the JCR index). Possible answers are: "Very relevant" (+1), "Relevant" (0), and "Not relevant" (−1).
e. The study has been cited by other authors (according to the *Scopus* citation index). Possible answers are: "Yes" (+1) cited by more than five authors, "Partially" (0) cited between one and five authors, and "No" (−1) if not cited.

3.1.1.5. Data extraction strategy. To each of the research questions, a series of possible answers was assigned (as can be seen in Table 3), which would allow the same data extraction criteria to be applied to all studies, enabling them to be classified according to these answers.

3.1.1.6. Synthesis methods. In the first place, a quantitative data synthesis of primary studies was carried out, based on:

- Representation through tables and/or graphs of the number/percentage of primary studies based on their answers in the research questions.
- In addition, a qualitative data synthesis of the primary studies was carried out, based on:
- Representation through tables and/or graphs of the primary studies according to the results of the quality evaluations carried out.

Table 3
Classification schema.

Research Questions	Answers	
RQ1. What proposals exist on sustainability maturity models?	**a.** Products/services	**e.** Facilities
	b. Processes/operations	**f.** Energy management
	c. Governance/management	**g.** Green IT
	d. Supply chain	**h.** Others
RQ2. What empirical evidence exists on sustainability maturity models?	**a.** Systematic mapping study/literature review	
	b. Case study	**d.** Survey
	c. Proposal	**e.** Others
RQ3. What standards, frameworks, or models are followed to measure the maturity of Green IT?	**a.** ISO/IEC 15504	**d.** PAM COBIT
	b. ISO/IEC 33000	**e.** Others
	c. CMMI	**f.** N/A

3.1.2. Execution stage

In the execution stage, the implementation of the revision protocol defined in the previous stage was carried out in three main phases:

1. Selection of potential studies: the search string was introduced on the *Scopus* database and a total of 85 studies were obtained. The selection criteria were applied to the abstracts of each paper and a total of 43 potential studies were finally obtained.
2. Selection of primary studies: the selection criteria were again applied to the potential studies, but this time applied to the entire study (full text), and a total of 27 primary studies were obtained (see Appendix A).
3. Quality evaluation and classification of primary studies: for each of the primary studies a quality evaluation following the quality assessment criteria and classification was carried out, based on the different answers to each of the research questions.

3.2. Results

3.2.1. RQ1: proposals for sustainability maturity models

The results of the research question RQ1 are shown by means of a graph, in Fig. 1.

On the one hand, it should be noted that more than half of the studies (55%) propose sustainability-related maturity models in which the processes and/or operations are taken into account, as well as the governance and/or management of an organization.

On the other hand, only 33% of studies ([S02], [S04], [S06], [S07], [S09], [S12], [S16], [S24], and [S25]) propose a maturity model related with Green IT.

3.2.2. RQ2: empirical evidence on the sustainability maturity models

In relation to the empirical evidence on sustainability maturity models (whose results are shown in Fig. 2), it is important to note that very few (only 30%) of the studies have been validated ([S02], [S04], [S10], [S11], [S15], [S18], [S19], and [S23]) by some case study or practical application, and only one of the studies [S09] validates its proposal by using a survey carried out with experts in the area in question.

3.2.3. RQ3: Standards, frameworks or models to measure the maturity of green iT

Among the standards, frameworks or models used or on which the proposed Green IT maturity models are based, 89% of the studies related to this type of model ([S02], [S04], [S06], [S07], [S09], [S12], [S16], and [S25]) follow CMMI (Capability Maturity Model Integration). Only study [S24] takes COBIT (Control Objectives for Information and related Technology) as a basis for proposing a model that measures the maturity of Green IT.

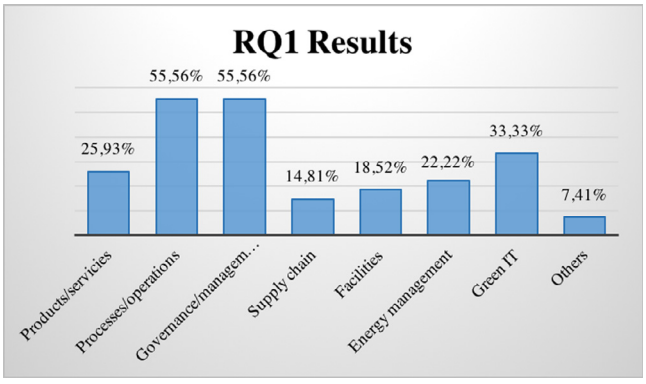

Fig. 1. Graph of results concerning research question RQ1 about proposals for sustainability maturity models.

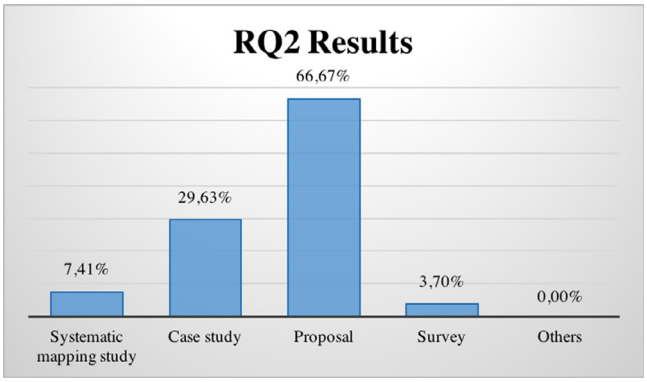

Fig. 2. Graph of results concerning research question RQ2 about empirical evidence on the sustainability maturity models.

3.2.4. Mapping results

After analyzing each of the research questions, the SMS can be seen to have established the following as general results:

- Sustainability maturity models typically focus on the areas of processes/operations and governance/management of an organization.
- Very few proposals on maturity models of sustainability and of Green IT in particular have been validated.
- CMMI is the most widely-used model when it comes to developing a Green IT maturity model.

Also, Table 4 shows the mapping results of each of the primary studies according to the research questions.

3.3. Discussion

The present SMS aims to discover the state of the art of maturity models of sustainability, and of Green IT in particular; the goal is to

Table 4
Mapping results of the primary studies.

ID	RQ1								RQ2					RQ3					
	a	b	c	d	e	f	g	h	a	b	c	d	e	a	b	c	d	e	f
S01[a]						X					X								X
S02			X				X		X	X						X			
S03[a]		X	X								X								X
S04[a]		X	X				X			X						X			
S05[a]		X	X		X	X					X								X
S06[a]	X	X	X		X		X				X					X			
S07[a]		X	X				X				X					X			
S08								X			X								X
S09[a]	X	X	X	X			X					X				X			
S10	X									X									X
S11[a]						X				X									X
S12		X					X				X					X			
S13		X							X		X								X
S14		X	X	X	X	X					X								X
S15					X	X				X									X
S16[a]		X	X				X				X					X			
S17	X										X								X
S18[a]	X	X								X									X
S19			X							X									X
S20				X							X								X
S21	X	X	X		X	X					X								X
S22			X								X								X
S23				X						X									X
S24		X	X				X				X						X		
S25[a]	X	X	X				X				X					X			
S26		X	X								X								X
S27								X			X								X

[a] Study found through snowballing.

identify the most important characteristics and possible shortcomings, so that a Green IT maturity model for the "Governance and Management Framework for Green IT" [7] can be identified.

Thus, after analyzing the results, this SMS demonstrates the limited number of studies related to maturity models of sustainability (only 27 studies have been found) and, in particular, of Green IT (only 9 studies in this field). This fact also points out the need to develop common, updated Green IT frameworks, as well as maturity models for these, if we are to establish, evaluate and improve the implementations carried out in this area.

Furthermore, this SMS shows the need to validate the maturity models proposed by the studies, since only 9 of the identified studies validate their proposal; and, in particular, in relation to the proposed Green IT maturity models, only 3 are validated: studies [S02] and [S04] carry out a validation through a case study, and study [S09] through a survey. Any development of a Green IT maturity model must be accompanied by its corresponding validation that allows it to be established as a correct, complete and applicable model in organizations.

It is important to highlight these 3 studies validated, since, to the best of our knowledge and following the results we have obtained from the quality assessment, they are the most complete and applicable proposals of Green IT maturity models identified through the SMS:

- The Green ICT maturity model proposed by Buchalcevova [S02] for Czech SMEs (*Small and Medium-sized Enterprises*) is a maturity model based on CMMI from the point of view of the areas of governance and management (mainly) of small and mediums organizations that use IT (not provide IT services). In the study, the author carries out a literature review and an internet search, through which 6 maturity models in the area of Green IT have been found and analyzed. It proposes and validates a new Green IT maturity model for SMEs which consists of 6 maturity levels (based on the maturity levels proposed by Philipson [S16]), 4 domains (Green of ICT, Green by ICT, People & Culture, and Governance), and 62 indicators to assess each of the items of the different areas of the domains. To validate this maturity model, the author carried out a case study based on a self-assessment form (based on this model) completed by 43 organizations.
- Curley et al. [S04] propose a complete and interesting CMMI-based maturity model for Green IT within the IT Capability Maturity Framework (IT-CMF). This maturity model is oriented to the areas of governance/management and processes/operations of the Green IT and consists of 5 maturity levels that the authors adapt to 4 areas or categories related to Green IT (Strategy and Planning, Process Management, People and Culture, and Governance). Also, for each of the maturity levels established, the authors define a series of key practices, outcomes and metrics to evaluate and improve the maturity of Green IT. In relation to the validation of the maturity model, the authors have applied and refined it through case studies in different organizations at international level.
- In the study [S09], Hankel et al., in cooperation with SURF (the Dutch higher education and research partnership for IT), propose a maturity model for Green IT based on the needs of the higher education and research institutions. This maturity model consists of 5 maturity levels and three domains (Green IT in the organization, Greening of IT, and Greening of operations with IT), in which the authors established different attributes to assess the areas of products/services, processes/operations, governance/management, and supply chain of the Green IT. In this case, a survey with 20 participants (mainly Dutch organizations) was carried out to validate this Green IT maturity model.

From the results of the SMS we can observe that there are no sustainability or Green IT models that follow ISO/IEC 15504, which demonstrates the importance of exploiting this area of ISO/IEC 15504-based maturity models of sustainability.

Therefore, the results of this SMS demonstrate the youth of this area of maturity models related to sustainability. Also, in relation to Green IT, it is not only important to develop common and updated frameworks, but also maturity models for these frameworks that allow for a gradual implementation, evaluation and improvement of Green IT practices carried out by organizations.

There has been a major boom in the area of sustainability and Green IT, the significance and relevance of which is increasing. Indeed, its implementation is becoming an essential and indispensable objective nowadays. Moving from the results of the SMS, the contribution of our work aims to fill this gap.

4. ISO/IEC 15504-based maturity model for the "Governance and Management Framework for Green IT"

The great growth of the idea of sustainability and, in particular, Green IT within organizations has led to the emergence of more and more research papers and isolated best practices in this respect.

That is why, in the absence of a framework or standard to carry out these Green IT practices, we have developed a first proposal of the "Governance and Management Framework for Green IT" [7] (GMGIT, hereinafter), based on the structure of enablers of the COBIT 5 framework [26], which aims to optimize and standardize the adoption of Green IT in organizations.

However, this first version of the GMGIT lacks a maturity model that allows organizations to gradually implement, evaluate and improve their maturity level in the area of governance and management of Green IT.

For this reason, in this paper we propose a maturity model (a process reference model) for the "Governance and Management Framework for Green IT", based on the default standard to evaluate and improve the maturity level in IT, ISO/IEC 15504.

The application of the different characteristics of the ISO/IEC 15504 standard to the "Governance and Management Framework for Green IT" is shown below.

First, ISO/IEC 15504 establishes 6 maturity levels, which we have adapted to the area of Green IT as follows:

- **Level 0 (Incomplete).** The organization does not take sustainability into account, and no Green IT practice is defined.
- **Level 1 (Performed).** The organization takes sustainability into account and carries out Green IT practices in the most critical aspects related to sustainability.
- **Level 2 (Managed).** The Green IT practices are clearly defined, established and managed throughout the different business areas, contributing to sustainability in and by IT.
- **Level 3 (Established).** The organization follows the recognized standards and best practices of Green IT (Green IT is correctly managed and governed), as well as identifies in a continuous way and ensures the compliance with the external requirements.
- **Level 4 (Predictable).** The organization carries out the monitoring, evaluation and measurement of implemented Green IT practices, through a set of sustainability metrics established for that purpose.
- **Level 5 (Optimizing).** The organization is fully committed to sustainability and is oriented towards the continuous improvement of implemented Green IT practices, by means such as for example detailed performance reports, exhaustive use of sustainability metrics, and management of the innovation process in sustainability.

Second, in each of these Green IT maturity levels, the different processes of the GMGIT have been encompassed, as shown in the Table 5. It is important to note that the GMGIT does not include all the processes defined by COBIT 5. Of the 37 COBIT 5 processes we have selected and adapted the 15 which we consider most directly related to this area, to Green IT.

Finally, we have described each of the GMGIT processes according

Table 5
ISO/IEC 15504 maturity levels of the processes of the "Governance and Management Framework for Green IT".

Process	Level 1	Level 2	Level 3	Level 4	Level 5
EDM01: Ensure governance framework setting and maintenance			X		
EDM02: Ensure benefits delivery			X		
EDM03: Ensure risk optimization					X
EDM04: Ensure resource optimization					X
EDM05: Ensure stakeholder transparency			X		
APO01: Manage the IT management framework		X			
APO02: Manage strategy		X			
APO06: Manage budget and costs		X			
APO08: Manage relationships		X			
BAI02: Manage requirements definition		X			
BAI03: Manage solutions identification and build		X			
BAI09: Manage assets	X				
DSS01: Manage operations	X				
MEA01: Monitor, evaluate and assess performance and conformance				X	
MEA03: Monitor, evaluate and assess compliance with external requirements			X		

to the ISO/IEC 15504 standard, i.e., identifying the attributes of each process, through which the compliance with said process can be analyzed. Table 6 shows by way of example the ISO/IEC 15504-based description of one of the GMGIT processes.

5. Validations

To verify the consistency and applicability of the ISO/IEC 15504-based maturity model for the GMGIT proposed in the previous section, we have carried out some validations through a focus group with experts and through a case study [31] in an IT service center.

5.1. Focus group

First of all, we decided to hold a focus group with experts in order to obtain a validation from a theoretical point of view, refining the proposed model before moving on to the practical level. These experts, five in all, belong to an IT department, have more than 10 years of experience in research and IT audits (with certification in CISA – *Certified Information Systems Auditor*), and are currently working on issues related to Green IT, IT, auditing and maturity models.

During the focus group, the GMGIT and the ISO/IEC 15504 maturity levels adapted to Green IT were presented and discussed first, especially the descriptions of maturity levels were discussed in order to keep them within the scope of the levels defined by ISO/IEC 15504. Following this, each of the experts was asked for his proposal about at what maturity level should be found each of the processes defined in the GMGIT and each of these proposals was discussed in group, refining them and reaching a common proposal.

After discussing the proposals of the experts and reaching a general proposal, we presented our proposal of the ISO/IEC 15504 maturity levels of each of the GMGIT processes to the experts. The common proposal previously obtained and our specific proposal were discussed and a final proposal of the ISO/IEC 15504-based maturity model for the GMGIT was achieved.

5.2. Case study: application in an IT service center

Next, we carried out a case study in an IT service center (for reasons

Table 6
ISO/IEC 15504-based description of the process "DSS01: Manage operations".

Attribute	Description	
Process ID	DSS01	
Process Name	Manage operations	
Process Description	Co-ordinate and execute the activities and operational procedures required to deliver internal and outsourced IT services, including the execution of predefined standard operating procedures and the required monitoring activities.	
Process Purpose	Deliver IT operational service outcomes as planned.	
Process Outcomes	As a result of successful implementation of "Manage operations": 1. The operations of Green IT are carried out following the policies, principles, strategy and goals of Green IT. 2. The standards, regulations and best practices of Green IT have been identified and implemented and are being complied with.	
Best Practices	**DSS01.BP1: Perform operational procedures.** Maintain and perform operational procedures and operational tasks of Green IT reliably and consistently. [Outcome: 1] **DSS01.BP2: Manage outsourced services.** Manage the operation of outsourced services so as to maintain their reliability and their consistency with the organization's Green IT. [Outcome: 1] **DSS01.BP3: Monitor IT infrastructure.** Monitor the IT infrastructure and events related to it, in an effort to ensure the alignment of all of them with the organization's Green IT. Store sufficient chronological information in operations logs to enable the reconstruction, review and examination of the time sequences of operations and the other activities surrounding or supporting those operations. [Outcome: 2] **DSS01.BP4: Manage the environment.** Maintain measures for protection against environmental factors. Install specialized equipment and devices to monitor and control the environment from the point of view of Green IT. [Outcome: 2] **DSS01.BP5: Manage facilities.** Manage facilities in line with laws, regulations, guidelines and other requirements related to Green IT. [Outcome: 2]	
Work Products	Inputs	Outputs
	Policies of Green IT. [Outcome: 1]	Operational procedures of Green IT. [Outcome: 1]
	Policies of management of the environment. [Outcome: 2]	Reports on the compliance of Green IT by third parties. [Outcome: 1]
	Policies of management of the facilities. [Outcome: 2]	Reports on the performance of the infrastructure of the IT, from the point of view of Green IT. [Outcome: 2]
		Alignment of Green IT with the management of the environment. [Outcome: 2]
		Alignment of Green IT with the management of the facilities. [Outcome: 2]

of confidentiality identified hereinafter as SC), which is responsible for the management of IT services of a university with over 30,000 students and is distributed across several campuses. Currently, the SC is beginning to implement sustainable measures in different areas of the business, including the following Green IT measures:

- Implementation of cloud computing services.
- Establishment of a corporate printing service, reducing the number of printing devices and raising awareness of the need to save ink and paper.
- Implementation of a service of withdrawal and recycling of electrical and electronic waste.
- Acquisition of IT equipment according to internationally recognized sustainability standards such as UE Energy Star v5, ISO 14001 o ISO 779/9296.
- Redesign of the data center, to improve energy efficiency and cooling.

Thanks to these Green IT measures, the SC has achieved good results in favor of environmental sustainability:

- Reduction of 20% of the energy destined for the cooling of the data center (obtaining a PUE – *Power Usage Effectiveness* of 1.4).
- Reduction of 52% of CO_2 emissions from university IT.
- Withdrawal of more than 48 tons of obsolete computer equipment for recycling.

From these results, it is estimated that the university has avoided the generation of 7261 kg of CO_2 and has produced a saving of 2631m^3 of water.

However, these Green IT practices have been carried out in an isolated manner and without following a specific framework or standard. For this reason, the SC decided to carry out an audit following the GMGIT, in order to know its current state of Green IT and adopt the framework to implement, evaluate and improve the Green IT (goal of the SC).

For our part, the main goal of this case study is based on practically applying for the first time the ISO/IEC 15504-based maturity model for the GMGIT developed, in order to refine it and improve its applicability in the real world.

So, in this audit, the high involvement of the SC with sustainability was observed, but many shortcomings were identified, especially in the definition and formalization of the Green IT practices.

Analyzing these results and applying them to the developed ISO/IEC 15504-based maturity model, we have concluded that the SC is partially at Level 1, as can be seen in Table 7.

Table 7
Fulfillment of the processes and their best practices of Level 1 in the SC.

Processes and their Best Practices of Level 1	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		

After presenting and analyzing the report of the audit of Green IT, the SC admitted the weaknesses and points of improvement found during the audit and felt satisfied with the expectations that they had in this regard. From the beginning, the SC was aware that the practices of Green IT they were carrying out did not follow any standard, these practices were implemented in a "disorganized" way and the organization was still in an initial phase of implementation. With the audit of Green IT, the SC had the expectation to get a first analysis about its current status of Green IT and, mainly, to obtain a guide to continue with the implementation and improvement of practices of Green IT.

So, we are currently working with the SC to overcome the deficiencies found, in order to reach the Level 1 of maturity of Green IT and start to work on the following levels, gradually implementing the Green IT and improving its maturity level in this area.

6. Conclusions and future work

Organizations, in their quest to improve and gain more and more value, have realized the enormous potential and impact of the idea of sustainability within their models and areas of the business [32]. That is why the organizations are increasingly rethinking their way of interacting with the environment and have begun to act in this regard in the area of IT, implementing Green IT initiatives in their processes and daily operations [3,4].

However, in this area of Green IT, organizations do not have any specific standards or frameworks to help them implement, evaluate and improve the Green IT practices that they carry out.

In order to overcome this obstacle, we have developed the "Governance and Management Framework for Green IT" and, in this paper, we have proposed an ISO/IEC 15504-based maturity model for this framework, with the intent to gradually help implement new practices of Green IT in an organization, as well as to evaluate and improve the maturity level of Green IT of an organization.

In the first validations of the proposed maturity model carried out, we have managed to consolidate at theoretical and practical level the utility of this model for organizations in this area of Green IT.

However, this is only a starting point and we will continue working in this area of Green IT, developing and improving through more validations both the "Governance and Management Framework for Green IT" and the maturity model proposed in this paper, making them into standard-compatible models.

On the other hand, we also intend to bring the ISO 14000 family of standards [33] closer to Green IT, in order to identify those characteristics that can be integrated into the "Governance and Management Framework for Green IT", serving as a guide for those organizations that seek a certification in this standard.

Sustainability is a reality in all areas of knowledge and a fundamental aspect for life, so it is our duty to defend this idea, to protect the environment, and work towards a better and more sustainable future.

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Appendix A. Primary studies selected in the systematic mapping study

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Appendix B. Processes of the "Governance and Management Framework for Green IT" organized by the ISO/IEC 15504 Maturity Levels

B.1. Level 1 (Performed)

B.1.1. BAI09: manage assets

- **Description of the process:** 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.
- **Statement of the purpose of the process:** Account for all the IT assets and optimize the value provided by these assets.

B.1.2. DSS01: manage operations

- **Description of the process:** Coordinate and execute the activities and operational procedures needed for the delivery of IT services, both internal and outsourced, including the execution of predefined standard operating procedures and the required monitoring activities.
- **Statement of the purpose of the process:** Deliver the results of the operational IT service as planned.

B.2. Level 2 (Managed)

B.2.1. APO01: manage the IT management framework

- **Description of the process:** Clarify and maintain the governance of the organization mission and vision of IT. Implement and maintain mechanisms and authorities for the management of information and the use of IT in the organization in the effort to support the governance objectives that are in harmony with the policies and guiding principles.
- **Statement of the purpose of the process:** Provide a consistent management approach to enable the organization governance requirements to be met, covering management processes, organizational structures, roles and responsibilities, reliable and repeatable activities, and skills and competencies.

B.2.2. APO02: manage strategy

- **Description of the process:** Provide a holistic vision of the current business and IT environment, the future direction, and the initiatives needed to migrate to the desired environment. Take advantage of the blocks and components of the organizational structure, including the outsourced services and the related capabilities that allow there to be an agile, reliable and efficient response to the strategic objectives.
- **Statement of the purpose of the process:** Align the strategic plans of IT with the business objectives. Clearly communicate the objectives and responsibilities associated with these, so that they may be understood by all, identifying the strategic options for the IT, while at the same time keeping them structured, and integrated into the business plans.

B.2.3. APO06: manage budget and costs

- **Description of the process:** Manage the IT-related financial activities in the business as well as in the IT functions, taking in the budget, costs and management of profits, together with the prioritization of the costs by means of the use of formal budget practices and a fair and equitable system of allocating costs for the organization. Consult the stakeholders to identify and control the total costs and benefits within the context of the strategic and tactical plans of the IT, taking corrective actions whenever necessary.
- **Statement of the purpose of the process:** Foster cooperation between the IT and the stakeholders of the organization in order to enable the effective and efficient use of the resources related to the IT, as well as to offer transparency and responsibility about the cost and business value of solutions and services. Allow the organization to take informed decisions as regards the use of IT solutions and services.

B.2.4. APO08: manage relationships

- **Description of the process:** Manage the relationships between the business and the IT formally and with transparency, making sure that these focus on the common objective of obtaining successful results for the organization, giving support to strategic objectives and within the limits set by the budget and acceptable risk. Base the relationship on mutual trust, using understandable terms and common language and willingness to accept accountability and responsibility in key decisions.
- **Statement of the purpose of the process:** Obtain better results and greater trust in IT and achieve effective use of resources.

B.2.5. BAI02: manage requirements definition

- **Description of the process:** Identify solutions and analyze requirements before acquisition or creation, to ensure that these will be in harmony with the strategic requirements of the organization and that they cover the business processes, applications, information/data, infrastructure and services. Coordinate with the affected stakeholders on the review of the viable options, including costs and related benefits, risk analysis and approval of the requirements and solutions proposed.
- **Statement of the purpose of the process:** Create the best-possible optimal solutions that fit the needs of the organization, while at the same time minimizing risk.

B.2.6. BAI03: manage solutions identification and build

- **Description of the process:** Establish and maintain the solutions identified, in line with the organization's requirements; these take in the design, development, purchase/contracting and association with suppliers/manufacturers. Manage the configuration, preparation of tests, running of tests, management of requirements and maintenance of business processes, applications, data/information, infrastructure and services.
- **Statement of the purpose of the process:** Establish specific and feasible solutions that are able to support the business strategy and operational objectives.

B.3. Level 3 (Established)

B.3.1. EDM01: ensure governance framework setting and maintenance

- **Description of the process:** Analyze and articulate the requirements of the IT governance of the organization and put in place and maintain the effectiveness of the structures, principles, processes and practices, with total clarity about the responsibilities and authority needed to achieve the mission, goals and objectives of the organization.
- **Statement of the purpose of the process:** Provide a consistent approach integrated and aligned with the scope of the governance of the organization. To ensure that the decisions related to IT have been adopted and that they are in harmony with the strategies and objectives of the organization; it has to ensure that monitoring of the processes is done effectively and transparently, that there is compliance with the legal and regulatory requirements, and that the governance requirements of the members of the Board of Directors have been reached.

B.3.2. EDM02: ensure benefits delivery

- **Description of the process:** Optimize the value added to the business from the business processes, IT services and IT assets which result from the investment made by IT, making sure that the costs are reasonable.
- **Statement of the purpose of the process:** Ensure an optimal value from the IT initiatives, services and assets; a cost-efficient delivery of the services and solutions, along with a reliable and precise vision of the probable costs and benefits, so that the business demands will be supported effectively and efficiently.

B.3.3. EDM05: ensure stakeholder transparency

- **Description of the process:** Ensure that the measurement and production of reports about the conformance and functioning of the IT of the organization are transparent, and that there is approval on the part of the stakeholders as regards the goals, metrics and corrective actions needed.
- **Statement of the purpose of the process:** Ensure that communication with the stakeholders is effective and opportune, and that a basis for the production of reports has been established; the aim will be to make the process work better and confirm that the strategies and objectives related with IT are in harmony with the strategy of the organization.

B.3.4. MEA03: monitor, evaluate and assess compliance with external requirements

- **Description of the process:** Evaluate the fulfilment of regulatory and contractual requirements, both in the IT processes and in the business processes that depend on the IT. Obtain assurance that the requirements have been identified and complied with and that IT compliance has been integrated into the overall compliance of the organization.
- **Statement of the purpose of the process:** Ensure that the organization satisfies all the external requirements that are applicable to it.

B.4. Level 4 (Predictable)

B.4.1. MEA01: monitor, evaluate and assess performance and conformance

- **Description of the process:** Collect, validate and evaluate business, IT and processes goals and metrics. Monitor that the processes are being carried out in accordance with the performance that has been agreed on, and in line with the goals and metrics; reports should be provided systematically and in a planned way.
- **Statement of the purpose of the process:** Provide transparency of performance and conformance, along with guidance towards the achievement of the objectives.

B.5. Level 5 (Optimizing)

B.5.1. EDM03: ensure risk optimization

- **Description of the process:** Ensure that the organization's appetite for, and tolerance of, risk are understood, and that the risk that is related to the use of IT with respect to the value of the organization is identified and managed.
- **Statement of the purpose of the process:** Ensure that IT-related organization risk does not exceed risk appetite and risk tolerance, the impact of IT risk to organization value is identified and managed, and the potential for compliance failures is minimized.

B.5.2. EDM04: ensure resource optimization

- **Description of the process:** Ensure that proper and sufficient IT-related capabilities (people, processes and technologies) are available to support the organization's objectives effectively at optimal cost.
- **Statement of the purpose of the process:** Ensure that the organization's resource needs are covered optimally, that the IT costs are optimized, that it will thus be increasingly likely that benefits will be obtained, and that there will be better preparation for future changes.

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