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Maturity model based on CMMI for governance and management of Green IT

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Abstract: Sustainability is a problem that is increasingly worrying organisations around the world, which has led them to adopt sustainable practices in their processes. From the point of view of one of the areas that have had the greatest impact in recent times in organisations, the area of information technology (IT), different sustainable practices have arisen in isolation, known as Green IT practices. So, a framework that organises and establishes these practices (until now isolated) is necessary in order to implement, assess, and improve the Green IT in organisations in an efficient, gradual, and integrated way. In this study, the authors propose a maturity model based on capability maturity model integration (CMMI), through which it is intended to help organisations gradually implement and improve through different levels of maturity, the governance and management of Green IT. The validations of this proposal carried out through experts and practical cases demonstrate the usefulness of this proposal when implementing, assessing, and improving the Green IT in organisations.

1 Introduction

In recent years, there has been growing awareness that it is very important not only to develop information systems that are more efficient, effective, and useful but also to aim for these to be sustainable.

In this respect, the area known as Green IT has gained constant relevance. The main objective of Green IT is to bring environmental sustainability [1] to the area of information technology (IT). This Green IT area 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' [2].

This idea of Green IT has become a determining area nowadays, as the concept of ecological awareness that it defends is increasingly present and is growing in importance within society, a society that is ever more committed to the protection of the environment. Green IT has thus been gaining relevance within organisations because it has become an important asset in the quest to add value to different areas of the business [3]. Moreover, the number of organisations that implement practices of Green IT within their processes and daily operations is therefore on the rise [4].

However, Green IT is a very young field [5] and, as it happens in the beginning, there is an increasing amount of best practices and research articles in this area [6], but there are no specific standards in this regard.

For this reason, we have developed the 'governance and management framework for Green IT (GMGIT)' [7], in order to define the elements and characteristics needed to establish the governance and management of Green IT in organisations, while at the same time providing a guide for carrying out Green IT audits.

In order to expand this framework and improve the performance of audits based on it, there is a need for a model through which an organisation can gradually implement the framework and improve its maturity level of Green IT. That model could also help in obtaining some type of certification in this field.

That is why in the present study we propose a maturity model for Green IT governance and management, based on the capability maturity model integration (CMMI) model, best known for evaluation and maturity of processes.

The rest of the present study is organised as follows: Section 2 describes the related work regarding the maturity models that currently exist from the point of view of different areas (IT, sustainability, and Green IT); Section 3 presents the proposal for applying the CMMI model to the 'GMGIT'; Section 4 shows the validations performed for the maturity model for Green IT proposed; finally, Section 5 presents the conclusions, along with the future work to be done in this area.

2 Related work

The different maturity models that exist in the main areas related to the present study, such as IT, sustainability, and Green IT, are analysed in the following sub-sections.

2.1 IT maturity models

In relation to IT, there are different maturity models, of which the most important and widely-used nowadays are:

- CMMI [8]: originally developed by Carnegie Mellon University and managed today by the CMMI Institute [acquired recently by Information Systems Audit and Control Association (ISACA)]. The main objective of this model is to assess and improve the processes of organisations within the scope of the development, operation, and maintenance of information systems and software products.
- ISO/IEC 15504 [9]: known as software process improvement capability determination (SPICE) was developed by the International Organisation for Standardisation (ISO) and International Electrotechnical Commission (IEC). This family of standards proposes a set of models for the evaluation and improvement of processes related to information systems. Based on this standard ISO/IEC 15504, in 2008, we developed a maturity model for software engineering [10], used by Asociación Española de Normalización y Certificación. Similarly, we have carried out another relevant contribution in this field, through which we have developed comparisons [11,

12] and support tools for harmonising multiple reference models that take into account similarities among existing models [13] when adopting new ones within an organisation (which we have applied in different contexts [14]).
- ISO/IEC 33000 [15]: developed by ISO and IEC, it is the new family of standards that replaces the ISO/IEC 15504 family for the assessment and improvement of the capacity and maturity of the processes of organisations. It involves a reorganisation and extension of the ISO/IEC 15504 family of standards.
- Maximising the combined effects of control objectives for information and related technology 5 (COBIT 5) and CMMI [16]: it is a proposal developed by ISACA. The objective of this proposal is to adapt the CMMI model to the COBIT 5 framework [17], in order to identify the maturity levels in which the different COBIT 5 processes should be.

2.2 Sustainability and Green IT maturity models

We carried out a systematic mapping study (SMS) in the area of sustainability maturity models [18], in which we have placed special emphasis on Green IT. The study demonstrates the small number of studies about maturity models related to sustainability (only 27 studies) and, in particular, to Green IT (only nine studies).

This SMS also shows the need to validate the proposals of maturity models in this area (only nine of the studies found validate their particular proposal), especially with regard to the Green IT maturity models proposed, of which only three are validated. These three studies are the most complete proposals of maturity models for Green IT that we have found

- Buchalcevova [19] proposed a Green Information and Communications Technology (ICT) maturity model for Czech small- and medium-sized enterprises (SMEs), based on CMMI and oriented to the governance and management of SMEs that use IT (not IT service providers). This model has a total of six maturity levels (based on the proposal of Philipson [20]), four domains (Green by ICT, Green of ICT, People & Culture, and Governance), and 62 indicators to evaluate the items of the domains. In order to validate this Green IT maturity model, a case study based on a self-assessment form was carried out by 43 organisations.
- The maturity model based on CMMI for Green IT within the IT capability maturity framework proposed by Curley *et al.* [21] is oriented to the governance, management, processes, and operations of Green IT. This model contains a total of five maturity levels adapted to four areas related to Green IT (governance, strategy and planning, process management, and people and culture). Regarding the validation of this Green IT maturity model, the authors have performed several case studies in different types of organisations at the international level.
- Hankel *et al.* [22], in collaboration with SURF (the Dutch higher education and research partnership for IT), carry out the proposal of a Green IT maturity model for the needs of higher education and research institutions. This model has a total of five maturity levels and three domains (greening of IT, Green IT in the organisation, and greening of operations with IT) to evaluate the areas of governance/management, processes/operations, products/services, and supply chain of Green IT. To validate this maturity model, a survey with 20 participants was performed.

At the same time, the SMS emphasises the importance of the CMMI model within the sustainability and Green IT maturity models, since this model is the most adopted and enhanced in all of the literature studies that we have identified to this point.

All of the above demonstrates how young the field of sustainability-related maturity models is. Also, in relation to Green IT, it points to the necessity to develop common and updated frameworks, as well as to establish maturity models for these frameworks, ones which would allow us to implement, assess, and improve the Green IT practices carried out in the different areas of the business.

3 Application of CMMI to the 'GMGIT'

In [7], we propose a first version of the GMGIT, which aims to simplify and normalise the adoption of Green IT in organisations. The GMGIT is based on the structure of enablers of COBIT 5 [17].

The GMGIT is still in development, however, as it stands, it lacks a model through which organisations can implement and improve their maturity level gradually from the point of view of the governance and management of Green IT. In the present study, we, therefore, propose a maturity model for the GMGIT.

From the different maturity models discussed in the previous section, we have not been able to use or adapt the specific Green IT maturity models that exist because they do not cover the necessary aspects and processes of governance and management that we have established in the GMGIT. For this reason, we have had to develop a maturity model adapted to these characteristics of the GMGIT and we decided to choose the CMMI model for application to the framework, since at present most proposals on maturity models related to Green IT (and to sustainability in general) follow this model, as can be seen in the results of the SMS in [18].

First of all, the CMMI model establishes five maturity levels that we have referred to based on the maturity levels proposed by Curley *et al.* [21] and we have adapted to the Green IT from the point of view of the GMGIT. The results are summarised as follows:

- Level 1 (initial). The organisation does not take sustainability into account and no Green IT practice is defined.
- Level 2 (managed). The organisation takes sustainability into account and carries out Green IT practices in the most critical aspects related to sustainability.
- Level 3 (defined). The Green IT practices are clearly defined, established and managed throughout the different business areas, contributing to sustainability in and by IT.
- Level 4 (quantitatively managed). The Green IT within the organisation is correctly managed and governed, carrying out the monitoring, evaluation, and measurement of implemented Green IT practices, through a set of sustainability metrics established for that purpose.
- Level 5 (optimising). The organisation is fully committed to sustainability and is oriented towards the continuous improvement of implemented Green IT practices by means of detailed performance reports, exhaustive use of sustainability metrics, and management of the innovation process in sustainability.

In addition, ISACA has started to work on this CMMI model to apply it to COBIT 5 [16], the framework the GMGIT is based on. To this end, ISACA has identified at which maturity levels the practices of each of the processes related to the governance and management of IT defined in its COBIT 5 [17] should be found.

The first version of the GMGIT does not include the 37 processes of COBIT 5. Rather, of these 37 processes, we have chosen 15 of them and adapted them to Green IT. These 15 are the ones we consider most closely related to the Green IT governance and management [7].

Tables 1–3 show a proposal on the maturity levels of the processes included in the GMGIT, as well as the practices of each of these processes (marking them with an 'X' at the level that should be found), taking as a guide the application of the CMMI model to the COBIT 5 framework carried out by ISACA. However, there are several aspects that should be considered in relation to the proposal made by ISACA:

- There are practices that are not yet analysed and which are not covered by any maturity level. In this case, we have marked with a 'G' the level that we consider correct for each of these practices.
- Some practices are at maturity levels that are not very appropriate and/or which should be found at other levels. For this, we have marked the practices that we do not agree with, using an 'I' do indicate the inappropriate level, i.e. not valid in

our proposal, and, if applicable, we marked with an 'A' the level which we consider appropriate for such practices.

Tables 4 and 5 show the justification of why those practices not covered by the model developed by ISACA were allocated to a specific maturity level, and Table 6, for its part, gives our justification of why we do not agree with the maturity level proposed by ISACA for certain practices.

Finally, it is important to highlight that in order to achieve conformity in each of the practices of each process of the GMGIT, a series of activities specific to Green IT must be carried out. These activities are defined in the GMGIT among other aspects such as goals, metrics, inputs, and outputs. Table 7 shows an example of the activities to be followed in order to attain the practices of the BAI03 process, related to manage solutions identification and build.

4 Preliminary validations

Once we developed the proposed maturity model based on CMMI for the GMGIT, we validated it to verify that the model is coherent and applicable in the real world. So we have applied a validation through two different approaches: (i) a focus group, carried out among experts of an IT department to whom the proposed model was proposed, (ii) two case studies carried out in an IT service centre (SC) and in a IT research institute (RI), following the guidelines proposed in [23]; for reasons of confidentiality the centres are identified as SC and RI.

4.1 Focus group

Before applying the maturity model in the real world, we decided to hold a focus group, i.e. a 'research technique that collects data through group interaction on a topic determined by the researcher' [24]. In this sense, Kontio *et al.* [25] establish a series of steps to follow in this type of technique, which we have based on the following subsections to carry out our focus group.

4.1.1 Planning the research: The main purpose (research problem) of this focus group is to obtain a preliminary validation from the theoretical point of view of the maturity model developed, through the presentation of the model, discussion and feedback obtained by the focus group participants.

4.1.2 Designing the focus group: First of all, we have selected five experts from an IT department. These are individuals with more than 10 years of research and auditing experience, and they meet specific prerequisites established on having a certification in Certified Information Systems Auditor and with work dedication on Green IT, IT, auditing, and/or maturity models.

On the other hand, the different points and main questions to be dealt with, through which we have divided the focus group, are the following:

i. Presentation and discussion of the proposal developed by ISACA for the application of CMMI to COBIT 5 [16]:
   a. Discussion about the maturity level at which the practices that are not yet covered in the proposal should be found. (At what level of the CMMI model should each not covered practice be found?).
   b. Discussion with the appropriateness of certain practices at the maturity levels that had been proposed; placing special attention to those practices with which we did not agree in our proposal of the maturity model. (Why should a specific practice not be at a certain level? What is the appropriate level for each practice?).
ii. Presentation and discussion of our proposal of the maturity model based on CMMI for the GMGIT, focusing in particular on those practices which are most critical, and on those where we disagree. (Are the descriptions of Green IT maturity levels adequate? Are the Green IT maturity levels correlated with the CMMI model or is there a gap between both? Do the levels of the practices not covered by the ISACA proposal in our model resemble the levels discussed in the previous phase? Is the appropriateness of the levels of the practices that were not agreed in the previous phase justified?)

4.1.3 Conducting the focus group: The focus group was held in October 2017, following the plan defined previously, and lasted 3 h.

4.1.4 Analysing the data and reporting the results: In the focus group, we first of all presented and discussed the proposal developed by ISACA for the application of CMMI to COBIT 5 [16]. In this first contact, we placed special emphasis on asking the experts about the level at which the practices not covered in the ISACA proposal should be found. At the same time, we also asked the experts about the appropriateness of each process and practice at the levels proposed by ISACA, thanks to which we obtained the discrepancy (and justification) of the experts regarding the three

Table 1 Maturity levels of the processes and their practices in the 'GMGIT'

Processes and their practices	Level 2	Level 3	Level 4	Level 5
EDM01: ensure governance framework setting and maintenance	**—**	**X**	**—**	**—**
EDM01.01: evaluate the governance system	—	G	—	—
EDM01.02: direct the governance system	—	X	—	—
EDM01.03: monitor the governance system	—	X	—	—
EDM02: ensure benefits delivery	**—**	**X**	**—**	**—**
EDM02.01: evaluate value optimisation	—	X	—	—
EDM02.02: direct value optimisation	—	X	—	—
EDM02.03: monitor value optimisation	—	X	—	—
EDM03: ensure risk optimisation	**X**	**X**	**—**	**—**
EDM03.01: evaluate risk management	—	X	—	—
EDM03.02: direct risk management	X	X	—	—
EDM03.03: monitor risk management	X	X	—	—
EDM04: ensure resource optimisation	**X**	**X**	**—**	**—**
EDM04.01: evaluate resource management	X	X	—	—
EDM04.02: direct resource management	—	X	—	—
EDM04.03: monitor resource management	—	X	—	—
EDM05: ensure stakeholder transparency	**—**	**X**	**—**	**—**
EDM05.01: evaluate stakeholder reporting requirements	—	X	—	—
EDM05.02: direct stakeholder communication and reporting	—	X	—	—
EDM05.03: monitor stakeholder communication	—	X	—	—

Table 2 Maturity levels of the processes and their practices in the 'GMGIT'

Processes and their practices	Level 2	Level 3	Level 4	Level 5
APO01: manage the IT management framework	**X**	**X**	**X**	**X**
APO01.01: define the organisational structure	X	—	—	—
APO01.02: establish roles and responsibilities	—	X	—	—
APO01.03: maintain the enablers of the management system	X	X	—	—
APO01.04: communicate management objectives and direction	—	G	—	—
APO01.05: optimise the placement of the function of Green IT	—	—	—	G
APO01.06: define information (data) and system ownership	X	—	—	—
APO01.07: manage continual improvement of processes	X	X	X	X
APO01.08: maintain compliance with policies and procedures	X	—	—	—
APO02: manage strategy	**—**	**X**	**X**	**X**
APO02.01: understand organisation direction	—	—	—	X
APO02.02: asses the current context, capabilities, and performance	—	—	G	X
APO02.03: define the target of the capabilities of Green IT	—	X	X	—
APO02.04: conduct a gap analysis	—	—	X	X
APO02.05: define the strategic plan and road map	—	X	—	—
APO02.06: communicate the strategy and direction of Green IT	—	G	—	—
APO06: manage budget and costs	**—**	**X**	**—**	**—**
APO06.01: manage finance and accounting	—	X	—	—
APO06.02: prioritise resource allocation	—	G	—	—
APO06.03: create and maintain budgets	—	X	—	—
APO06.04: model and allocate costs	—	X	—	—
APO06.05: manage costs	—	X	—	—
APO08: manage relationships	**—**	**X**	**X**	**X**
APO08.01: understand business expectations	—	X	—	—
APO08.02: identify opportunities, risk and constraints for Green IT to enhance the business	—	—	—	X
APO08.03: manage the business relationship	—	X	—	—
APO08.04: co-ordinate and communicate	—	G	—	—
APO08.05: provide input to the continual improvement of services	I	X	—	X
BAI02: manage requirements definition	**X**	**X**	**—**	**—**
BAI02.01: define and maintain business functional and technical requirements	X	X	—	—
BAI02.02: perform a feasibility study and formulate alternative solutions	—	X	—	—
BAI02.03: manage requirements risk	X	X	—	—
BAI02.04: obtain approval of requirements and solutions	X	X	—	—
BAI03: manage solutions identification and build	**X**	**X**	**—**	**—**
BAI03.01: design high-level solutions	—	X	—	—
BAI03.02: design detailed solution components	X	X	—	—
BAI03.03: develop solution components	—	X	—	—
BAI03.04: procure solution components	—	X	—	—
BAI03.05: build solutions	X	X	—	—
BAI03.06: perform quality assurance	—	X	—	—
BAI03.07: prepare for solution testing	—	X	—	—
BAI03.08: execute solution testing	—	X	—	—
BAI03.09: manage changes to requirements	—	X	—	—
BAI03.10: maintain solutions	X	G	—	—
BAI03.11: define services of Green IT and maintain the service portfolio	—	X	—	—

practices shown in Table 6. Thus, from these initial discussions with the experts, we obtained a preliminary mapping on the maturity levels in which each of the COBIT 5 processes that we chose for the GMGIT (and their practices) should be found.

After discussing this proposal from ISACA and obtaining the preliminary mapping of the maturity levels of the processes and their practices, we presented our proposal of the maturity model based on CMMI for the GMGIT, placing special emphasis on reviewing, comparing, and discussing the maturity level of all the processes and practices with the mapping of the maturity levels obtained in the previous phase. Thanks to these last discussions, we managed to reinforce our vision of our proposed model, since we agree with the experts' vision on the levels of each process and practice. Similarly, we also obtained more solid and valid justifications thanks to the debate between experts and the different points of view (justifications are shown in Tables 4–6).

By means of this focus group, we were able to refine and verify the suitability of both the proposed maturity levels and of the processes and practices at each of these maturity levels, as well as to consolidate all of these theoretically, obtaining a final proposal of the maturity model based on CMMI for the GMGIT.

4.2 Application in an IT SC

To validate the model from a practical point of view, we selected the method of case study, i.e. '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' [26].

4.2.1 Method and case selection: The use of case studies is especially appropriate for all new research fields [27]. That is why we have chosen to carry out this type of methodology due to the

youth of the Green IT area, which is still in the exploratory phase. In the same way, thanks to the case study, we can answer exploratory research questions such as

- Are the established Green IT maturity levels adequate to the organisational processes?
- Are the processes and practices at a correct level with respect to the organisational initiatives?
- Is the model developed applicable in real life?

In order to conduct the case study, we have tried to select an organisation that is most appropriate and representative of the topic in question, and, therefore, we have chosen, in the first place, the SC.

The SC is responsible for managing the IT services of a university of more than 30,000 students, distributed over several campuses. This centre is committed to sustainability, and has carried out some measures related to Green IT

- Use of cloud computing services.
- Implementation of a corporate printing service in order to reduce the number of printing devices and raising awareness to save ink.
- Establishment of service of withdrawal and recycling of electrical and electronic waste.
- Acquisition of IT equipment that complies with internationally recognised sustainability standards such as EU Energy Star v5, ISO 14001, or ISO 779/9296.

Table 3 Maturity levels of the processes and their practices in the 'GMGIT'

Processes and their practices	Level 2	Level 3	Level 4	Level 5
BAI09: manage assets	**—**	**X**	**—**	**X**
BAI09.01: identify and record current assets	—	G	—	—
BAI09.02: manage critical assets	—	G	—	—
BAI09.03: manage the asset life cycle	—	G	—	—
BAI09.04: optimise asset costs	—	X	—	G
BAI09.05: manage licenses	—	G	—	—
DSS01: manage operations	**X**	**X**	**—**	**—**
DSS01.01: perform operational procedures	X	X	—	—
DSS01.02: manage outsourced services	X	G	—	—
DSS01.03: monitor IT infrastructure	X	G	—	—
DSS01.04: manage the environment	X	G	—	—
DSS01.05: manage facilities	X	X	—	—
MEA01: monitor, evaluate and assess performance and conformance	**—**	**—**	**X**	**X**
MEA01.01: establish a monitoring approach	—	—	G	—
MEA01.02: set performance and conformance targets of Green IT	—	—	G	—
MEA01.03: collect and process performance and conformance data of Green IT	—	—	G	—
MEA01.04: analyse and report on the performance of Green IT	—	I	A	X
MEA01.05: ensure the implementation of corrective actions	—	I	A	X
MEA03: monitor, evaluate, and assess compliance with external requirements	**—**	**—**	**X**	**X**
MEA03.01: identify external compliance requirements of Green IT	—	—	G	—
MEA03.02: optimise response to external requirements of Green IT	—	—	—	G
MEA03.03: confirm compliance with the external requirements of Green IT	—	—	G	—
MEA03.04: obtain assurance of compliance with the external requirements of Green IT	—	—	—	X

Table 4 Justification of practices not covered

Practices	Justification
EDM01.01	level 3: a necessary practice when defining and establishing the Green IT governance, which is carried out at level 3
APO01.04	level 3: up to level 3 the management objectives and direction are not clearly defined, so once they are established it is at this level that they are to be communicated
APO01.05	level 5: any practice related to optimisation is always carried out at the highest level since these are advanced tasks
APO02.02	level 4: the practices related to aspects of monitoring, evaluation and/or measurement are found in level 4, once everything is correctly defined and established
APO02.06	level 3: it is necessary to communicate the strategy and direction of Green IT once these are defined, something that is carried out at level 3
APO06.02	level 2: the management of the budget and costs is a fundamental process, and all its practices must be done from the beginning, which is why it is necessary for this practice to be at level 2
APO08.04	level 3: the management of communications and coordination with the stakeholders must be carried out to ensure the correctness and adequacy of the established Green IT practices, which is carried out at level 3
BAI03.10	level 3: the maintenance of solutions must start at level 2, but it is also important that it should be at level 3 since the definition and establishment of other aspects of Green IT related to other practices can affect this practice (by changing it, updating it)
BAI09.01	level 3: the practices related to the management of assets must be carried out at level 3 when defining and establishing the different aspects necessary for the formalisation of Green IT
BAI09.02	level 3: the practices related to the management of assets must be carried out in level 3 when defining and establishing the different aspects necessary for the formalisation of Green IT
BAI09.03	level 3: the practices related to the management of assets must be carried out in level 3 when defining and establishing the different aspects necessary for the formalisation of Green IT
BAI09.04	level 5: any practice related to optimisation is always carried out at the top level since these are advanced tasks

- Redesign of the data centre, in order to improve energy efficiency and cooling.

With these measures, the SC has accomplished remarkable results for environmental sustainability:

- Reduction of 20% of the energy destined for the cooling of the data centre (obtaining a power usage effectiveness of 1.4).
- Reduction of 52% of CO_2 emissions.
- Withdrawal and recycling of more than 48 tonnes of obsolete IT equipment.

Thanks to these results, the SC has estimated that they have avoided the generation of 7261 kg of CO_2 and saved 2631 m^3 of water.

Therefore, we can observe the involvement and contribution of the SC with sustainability and Green IT, thanks to the initiatives it has carried out and results obtained, which makes it a representative case study in our research goal to define and, mainly, validate the maturity model based on CMMI for the GMGIT.

4.2.2 Data collection: Until now, the SC has been carrying out sustainability practices in an unorganised manner and following its own criteria. That is why, once the GMGIT was known and the development of the maturity model was developed, the SC decided to carry out a practical case in this regard, aiming to ascertain its current state and to take measures to improve in this area of Green IT.

Thus, the data collection was carried out during June 2017 and a qualitative methodology was carried out (based on observations,

Table 5 Justification of practices not covered

Practices	Justification
BAI09.05	level 3: the practices related to the management of assets must be carried out at level 3 when defining and establishing the different aspects necessary for the formalisation of Green IT
DSS01.02	level 3: the practices related to the management of operations should start at level 2, but should also be considered in level 3, since the definition and establishment of other aspects of Green IT may affect these practices
DSS01.03	level 3: the practices related to the management of operations should start at level 2, but should also be considered in level 3, since the definition and establishment of other aspects of Green IT may affect these practices
DSS01.04	level 3: the practices related to the management of operations should start at level 2, but should also be considered in level 3, since the definition and establishment of other aspects of Green IT may affect these practices
MEA01.01	level 4: the practices related to aspects of monitoring, evaluation and/or measurement are found at level 4, once everything is correctly defined and established
MEA01.02	level 4: the practices related to aspects of monitoring, evaluation and/or measurement are found at level 4, once everything is correctly defined and established
MEA01.03	level 4: the practices related to aspects of monitoring, evaluation and/or measurement are found at level 4, once everything is correctly defined and established
MEA03.01	level 4: the practices related to aspects of monitoring, evaluation and/or measurement are found at level 4, once everything is correctly defined and established
MEA03.02	level 5: any practice related to optimisation is always carried out at the top level since these are advanced tasks
MEA03.03	level 4: the practices related to aspects of monitoring, evaluation and/or measurement are found in level 4, once everything is correctly defined and established

Table 6 Justification of our disagreement with certain practices

Practices	Justification
APO08.05	level 2 is not appropriate since the continuous improvement of the processes cannot be carried out at a level where the Green IT processes are not yet defined and established correctly; this definition starts to develop from level 3
MEA01.04	level 3 is not appropriate since practices related to monitoring, evaluation and/or measurement should be found at level 4, once everything is correctly defined and established
MEA01.05	level 3 is not appropriate since practices related to monitoring, evaluation and/or measurement should be found at level 4, once everything is correctly defined and established

Table 7 Activities specific to Green IT of the BAI03 process

Practices	Activities
BAI03.01	1. define the specifications of Green IT in line with the high-level design
BAI03.02	1. ensure that Green IT is taken into account in the design of components
BAI03.03	1. ensure that all the components implement the solutions of Green IT that have been established for each one of them
BAI03.04	1. ensure that the acquisition plan is aligned with the requirements and objectives of Green IT
BAI03.05	1. ensure that the solutions are built following the requirements of Green IT
BAI03.06	1. assure the quality of the solutions of Green IT and the inclusion of the requirements of Green IT in the quality assurance plan
BAI03.07	1. ensure that the test plans incorporate evaluations of Green IT
BAI03.08	1. ensure, by means of the tests, that the requirements of Green IT that have been established are followed at all times, and carry out corrective measures to assure that they are fulfilled
BAI03.09	1. carry out changes to the requirements of Green IT and manage these changes so that they conform to the expected results of Green IT
BAI03.10	1. ensure that the maintenance of solutions also incorporates the maintenance of the aspects of Green IT2. ensure that the changes carried out in requirements and/or objectives of Green IT is reflected in the maintenance of solutions
BAI03.11	1. identify and define the services of Green IT needed to fulfil the requirements and goals of Green IT and of the organisation, as well as to comply with legal and regulatory requirements

Table 8 Fulfilment of processes and their practices of level 2 of maturity in the SC

Practices	Yes	Partially	No
EDM03: ensure risk optimisation	—	—	X
EDM03.02: direct risk management	—	—	X
EDM03.03: monitor risk management	—	—	X
EDM04: ensure resource optimisation	—	—	X
EDM04.01: evaluate resource management	—	—	X
APO01: manage the IT management framework	—	X	—
APO01.01: define the organisational structure	—	—	X
APO01.03: maintain the enablers of the management system	—	—	X
APO01.06: define information (data) and system ownership	—	—	X
APO01.07: manage continual improvement of processes	—	X	—
APO01.08: maintain compliance with policies and procedures	—	—	X
APO06: manage budget and costs	—	X	—
APO06.01: manage finance and accounting	—	—	X
APO06.02: prioritise resource allocation	—	X	—
APO06.03: create and maintain budgets	—	—	X
APO06.04: model and allocate costs	—	—	X
APO06.05: manage costs	—	—	X
BAI02: manage requirements definition	—	—	X
BAI02.01: define and maintain business functional and technical requirements	—	—	X
BAI02.03: manage requirements risk	—	—	X
BAI02.04: obtain approval of requirements and solutions	—	—	X
BAI03: manage solutions identification and build	—	X	—
BAI03.02: design detailed solution components	—	—	X
BAI03.05: build solutions	—	—	X
BAI03.10: maintain solutions	—	X	—
DSS01: manage operations	—	X	—
DSS01.01: perform operational procedures	—	X	—
DSS01.02: manage outsourced services	X	—	—
DSS01.03: monitor IT infrastructure	X	—	—
DSS01.04: manage the environment	—	—	X
DSS01.05: manage facilities	X	—	—

Yes: all Green IT audit questions related to this process have an affirmative answer (except those that are N/A); partially: some Green IT audit questions related to this process have an affirmative answer while others have a negative answer (except those that are N/A); no: all Green IT audit questions related to this process have a negative answer (except those that are N/A).

interviews, collection of documents etc.) since the nature of this type of case study based on an audit does not give rise to another type of methodology.

So, a Green IT audit was carried out, following the GMGIT audit guide, consisting of a series of interviews both with senior management and main IT managers, collection of documents, and reports related to Green IT activities, as well as on-site observations to verify the correct application of the initiatives of Green IT and detect problems and risks in this regard. During the interviews, each of the audit questions established in the GMGIT [7] was carried out, filling out a checklist on the compliance or not of each specific practice.

It is noteworthy that we have evaluated all the processes established in the GMGIT through each of the audit questions of each process, however, this is not necessary since the first levels must be evaluated and, if these levels are met, evaluate higher levels. However, we have done this in order to check the adequacy of the different processes and practices with respect to their levels of maturity, i.e. to corroborate that the processes of the higher levels are there and not in the lower levels since the organisations need to have the base of the lower levels to be able to carry out the practices of the processes of the higher levels.

4.2.3 Data analysis: Analysing the results obtained through each answer to the audit questions and evidence found, and applying them to the maturity model based on CMMI developed, we have determined that the SC is partially at level 2 of maturity (see Table 8), since most of the processes and practices of level 2 are not taken into account or are not formalised.

The results of this audit showed the high commitment to sustainability on the part of the SC but identified the need to define and formalise the sustainability and Green IT practices carried out, establishing a basis for governance and management of this area.

We are currently working with the SC to address the problems/deficiencies found in the audit, so that achievement of level 2 can be accomplished and in order that work on the processes and practices at the subsequent levels can be started.

Thanks to this case study, therefore, we have, on the one hand, offered the SC a roadmap to follow for gradual implementation of Green IT and for the improvement of the centre's maturity level in this area. In addition, we have achieved a first validation of the maturity model based on CMMI for the GMGIT proposed.

Through this validation, we have reinforced and refined the fundamental and practical aspects of the maturity model based on CMMI for the GMGIT proposed, and the feasibility and applicability of the processes and practices in the lower maturity levels have been validated.

4.2.4 Follow-up audit: One year after the first audit performed at the SC, a follow-up audit was conducted to check the progress made regarding Green IT.

During this audit, we were able to observe certain improvements in the management of Green IT practices, among which we should highlight the full compliance with the DSS01 process and great progress in the BAI02 and BAI03 processes. This continues to demonstrate the need and usefulness of the GMGIT and a maturity model such as the one proposed in this study.

Similarly, the SC has commented us about the need to continue expanding both the framework and the maturity model with new

processes that are related to the management of programmes and projects, of changes, and of problems, among others. This is because they currently consider these processes in their operations related to Green IT, but they are not reflected in the GMGIT and in the maturity model.

4.3 Application in a RI

Following the same methodology and logic as with the first case study, we also conducted a second audit in the RI. This organisation is dedicated to research within the IT area and is currently working on issues related to Green IT.

In fact, the RI has achieved very good results in the research and own implementations that it is carrying out regarding Green IT. These include the analysis and alignment of the different goals between environmental sustainability and software development [28], as well as the development of a device capable of analysing the consumption of any type of software [29].

Regarding the results of the Green IT audit performed, the RI is at level 2 of maturity. In comparison with the first case study, the RI fully complies and has very well implemented the processes of BAI02 and BAI03, partially complies with the APO06 and DSS01 processes, and has not implemented any other practice of the rest of the processes.

4.4 Threats to validity

In relation to the four aspects of the validity defined by Runeson *et al.* [23], the following should be considered:

- Construct validity: we have adopted the definitions of two well-known frameworks/models, on the one hand, in relation to the GMGIT, we have followed the definitions and elements related to the governance and management defined in COBIT 5, while, on the other hand, we have embraced the definitions, levels and most important characteristics of the CMMI model; therefore, in this respect there are no discrepancies between the researchers and the practitioners. However, the issues related to the Green IT area may not be interpreted in the same way by researchers and practitioners (mainly due to the novelty of this area), so it is in these aspects where more emphasis we have devoted, trying to define and explain them in detail to avoid these discrepancies.
- Internal validity: the main threat to internal validity is related to the problems that the audited organisations may have to carry out the audit and/or to make the implementation of the GMGIT proposed. This is due to lack of time/resources, lack of involvement and commitment from senior management, internal discrepancies and with the researchers etc. That is why to mitigate this threat, we have carried out a formal presentation of both the GMGIT and the maturity model based on CMMI to the senior management and main IT managers of the organisations (to obtain their commitment), and an analysis of the organisations to, on the one hand, determine if they have appropriate time and resources to perform the audit and implementation of the GMGIT, and, on the other hand, to assess their level of interest and the associated risks in this regard.
- External validity: the case studies were carried out in two different organisations but in the same area: one dedicated to the management of IT services and another one dedicated to research in the IT area. Although in general IT centres and data processing centres usually have infrastructures, stakeholders, and problems that are similar, there may be discrepancies between organisations that have different business objectives. That is why to mitigate this threat and so that the GMGIT and the maturity model based on CMMI can be applied in different types of organisations, we will carry out more case studies in different organisations in order to generalise the findings and refine both the GMGIT and the maturity model based on CMMI.
- Reliability: in order to reduce the bias among the authors, the analysis and transcription of data of the focus group and interviews (data collection techniques defined at [30]) were carried out independently by each author. However, all authors/researchers collaborate closely on the same issues, so in the future, we intend to prepare more detailed documentation so that other external researchers can apply and validate both the GMGIT and the maturity model based on CMMI.

5 Conclusions and future work

As Marc Andreessen remarks 'software is eating the world' and within organisations, IT has become a critical area for adding business value. Organisations around the world, following the 'green revolution', have begun to take action in the area of IT, which has led to Green IT initiatives gaining more and more ground within organisations [31], offering benefits which go far beyond the economic sphere [3, 4].

However, organisations are facing a major obstacle in this field of sustainability, and, in particular, in the area of Green IT, as there is a lack of guidelines and/or standards that help them to implement Green IT practices and improve in this area.

The maturity model based on CMMI for the GMGIT proposed in this study can help to evaluate the maturity level an organisation is found to be in regarding Green IT, so that it may then gradually implement new practices and improve in this area from the point of view of the governance and management of Green IT.

In the validations of the proposed maturity model based on CMMI that have been performed, we have in fact already been able to observe the usefulness of the model for organisations in this field of Green IT and, in particular, in the governance and management of Green IT.

This is only the beginning; however, there is still much to be done, and we believe that it is vital to continue working towards sustainability and to carry on developing and improving the proposed model, which is why it is necessary to carry out more validations of the maturity model for the GMGIT, applying it systematically in various organisations through case studies [23]. We also hope to learn lessons and gain knowledge about the problems and/or difficulties that exist or arise when developing and applying a model to measure and determine maturity in the area of Green IT.

Among the lessons learned that we have already obtained in the validations performed, we have observed the need to expand the GMGIT and the maturity model with more processes that cover all the needs of the business with respect to Green IT (such as management of risk, of problems etc.).

On the other hand, another line of future work that we also have in mind is to update the maturity model presented in this study to the new version of CMMI v2.0 [32]. This will allow further refinement of the approach and model to apply them to a larger number of different kinds of organisations, having a version with all the new features included.

In addition, another topic we intend to address is the application of the ISO 14000 family of standards [33] within Green IT, aiming to identify those elements that can be applied/adapted in the framework. This, together with the proposed maturity model, will serve as a guide for organisations seeking certification in this standard.

Environmental sustainability is a fundamental characteristic nowadays; it is not a trend, but rather a reality in all areas of knowledge. It is our duty to work towards protecting the environment and achieving sustainable development in all areas.

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