IT Environmental Efficiency Evaluation

Jorge Emanuel Roxo Azul Cavaleiro

57011, Mestrado em Engenharia Informática e Computadores, Instituto Superior Técnico, Tagus Park

jorge.cavaleiro@ist.utl.pt

Abstract. Nowadays, subjects related to CO2 emissions reduction and operation cost cuts are hot topics for organizations across the world.

The purpose of this work is to provide a *framework* that allows estimating power usage and the footprint of the IT infra-structure. In order to accomplish this research goal, a generic methodology has been developed, based on Load indicator, to estimate the energy consumption of all kinds of systems.

Having hold of those estimated figures of power usage, KPI's could be calculated, allowing a benchmark analysis, to compare it with the best practices, other organizations or other possible future scenarios.

This framework considers a last step called IT Optimization which consists of a set of possible improvements to apply to the Technological layer of Enterprise Architecture.

This framework has been tested with two different equipments: Computers/Servers and Printers. The results show that this approach leads to figures close to the real consumption values and, due to this generic solution, it can be extended to other kind of IT equipments existent in the Technological layer of the Enterprise Architecture.

Keywords: Green IT, Environmental Efficiency, Information Technology Evaluation, Enterprise Architecture, Energy Consumption Estimation

1 Introduction

At the present, the usage rate of the information systems is growing [1; 2]. One of the consequences of the increase in the active systems number and its working load [3] is the rise of energy demands. This combined with the need for operational cost cuts and the implementation of a marketing strategy to decrease the ecological footprint in the organization, emphasizes the need for action on this environmental challenge [4; 5]. These concerns are at the heart of Green IT.

The approach to Green IT behind this work is broader than Information Technology (IT) infrastructure optimization. It establishes a first step to identify the problems existing in the infrastructure followed by a benchmark of those problems and ends with an association between problem clusters and the effort to solve them.

This work aims at linking the areas of enterprise architectures, cost of assets and technological infrastructure optimization to address the concerns mentioned before.

On the first section, this paper presents a review of the latest progresses in the areas related to the work subject (2). On the next two sections (3 and 4) it describes the problem addressed and its architecture solution. The final sections present the results of the validation tests using the proposed solution (5) and the work conclusion (6).

2 Related Work

The next sections describe the latest developments of the areas considered relevant for this work (Enterprise Architecture, Cost of Operational Assets and IT Efficiency Improvement Technologies) and give a set of regulations and incentives to improve the organization's eco-footprint.

2.1 Enterprise Architecture

Archimate [6] defines a meta-model for business architecture modeling. This meta-model is divided in three organizational layers (business, applications and technology) and has three organizational aspects (passive structure, active structure and behavior).

In the scope of this work the Technology Layer is the most relevant one. This layer makes the characterization of systems specifications and networks configurations needed to support the applications identified on the upper level.

One ability of this Framework consists on the quantitative analysis of the architecture [7]. This evaluation method grants the possibility of cost accounting of the systems operation using a formal-based method.

Another similar tool is CEO Framework (FCEO) [8]. This framework has the purpose to model on a non-ambiguous way the organizational targets, business processes and all the resources used by the organization to reach the goals defined.

Referring to Archimate, the FCEO has an extended meta-model with more layers considered, more concepts and a graphical representation based on the UML language. On a current version no quantitative or qualitative evaluation method is described for FCEO.

2.2 Cost of Operational Assets

To determine the infra-structural locations that need optimization, a cost analysis is required.

On the context of this work the cost is defined according to the energy consumption of the electronic equipments and the related CO_2 emissions.

To get the operation cost of a certain asset multiple techniques are available. Next there will be described the more used ones in the industry.

The Activity-Based Costing (ABC) [9] allows the identification of the costs by getting into account three points: the *Resources*, which are the economic elements needed for the operation; the *Activities* or *Processes*, which represents the entities that allow the organization to create value; and the *Objects*, the stakeholders of the Activities which justify their existence.

Another technique used these days is the Service-Based Costing (SBC) [10]. This process was built with ITIL v3 using an approach similar to ABC. The difference to ABC is related to the target of cost charge. On SBC the accounting is over the Services rendered by the organization, instead of the Activities identified, as is on ABC. This approach allows a better perception of the impact of the indirect costs.

2.3 IT Efficiency Improvement Technologies

With the rise of energy needs associated to the growth rate of IS usage, the research of new technologies and searching for new approaches to reduce energy consumption and environmental impacts has created new concerns for the IT research community.

One of the spots with the weightiest responsibility to the organizational energy consumption is the Data Centre [11]. For that reason some optimizations and monitoring methods have been developed, such as power usage controlling metrics [12], chillers operation optimization [13], optimization of room ventilation dynamics [14] and the reutilization of the heat produced by the servers [15] are some examples.

Other environmental efficiency improvements can be made adopting new technologies like Virtualization [16], Cloud-Computing [17] or storage consolidation plans [18] to decrease waste of disk usage.

Another key factor is human behavior. There are some daily actions that have energy consumption and environmental impact. Some solutions might be to shut down computer screens while not being in use or reutilize paper to test prints.

2.4 Environmental Regulation

In recent years there was a rise in enterprise management concerns about climate change and CO_2 emissions.

The Kyoto Protocol [19] and the Copenhagen Agreement [20] are the latest relevant developments in International action to fight global warming. Both documents are complemented by the contribution of organizations like Energy Star [21] that establishes new goals and standards for reducing energy consumption and CO_2 emissions of technology equipments.

2.5 Thematic Interrelation

Nowadays topics related to the environment are getting higher importance, as shown in chapter 2.4. Knowing that the IT field is responsible for a high rate of CO_2 emissions, the environmental regulation and the growing of its importance are factors that show the need to improve the environmental efficiency of IT.

This leads us to the efficiency improvement techniques shown in chapter 2.3. The vendors claim results for those techniques and technologies showing that can improve the eco-footprint of an IT infrastructure. But, are the results achieved in a case A better than those achieved in a case B? And worldwide company's has enough money to buy and implement these technologies? If not, where do they must act first?

For that reason matter there is a need for the cost of operational assets, to be adapted to the IT reality and to understand which equipments are less eco-friendly. The techniques given in chapter 2.2 are just examples that could help in the development of a model to environmental for cost estimation related of the IT infrastructure.

But those techniques don't capture the relations between IT equipments. Furthermore they don't capture the relation between IT infrastructure and business needs. So, if we want to estimate the environmental cost of high level instructions (like emitting a sale order or processing a customer claim) the costing techniques can't do it by themselves.

That is why we need the EA to establish and represent the relations between the different objects that matter for each situation.

This will show the importance and the relation of each point previously presented on this chapter.

Further in this paper it is used the Archimate as the EA meta-model. Its international importance, its integration with TOGAF and its evaluation methodology similar to the ABC technique are the key factors for this choice.

The techniques presented are some of the more popular in the market. These techniques show that the IT operation can be optimized.

Finally, the environmental regulation chapter only emphasizes the need to act on this matter and shows that this theme has a growing relevance.

3 Research Problem

Considering the issues presented in Chapters 1 and 2, the research problem addressed is

- Could it be possible, based on the technological architecture of an organization, and starting with the data related to his energy consumption, use it to identify problems of environmental efficiency in the IT infrastructure?

Out of this work scope are subjects like automatic architecture identification or the using of other EA layers above technology.

3.1 Research Hypotheses

Based on the problem question presented on the previous chapter, four research hypotheses have been developed to guide and help on the execution of the present work. Those hypotheses are:

1. It is possible to model, using the EA, information related to the environmental efficiency of technological equipments that supports enterprise operation.

2. It is possible to create a costing model that, using the information modeled by the previously hypothesis, does the environmental efficiency evaluation of the IT equipments of an organization.
3. Using the evaluation described in the previous hypothesis it is possible to determine existing problems of environmental efficiency in the IT infrastructure considered and compare between different possible architectures.
4. There are available IT techniques and technologies that solve or mitigate the problems of environmental efficiency of an IT infrastructure.

3.2 Goals

The final goal of this work is to link the four areas described in the Related Work chapter in a model and methodology that allows the estimation of the environmental efficiency of an IT infrastructure in order to find out problems of eco-efficiency.

4 Adopted Approach

It has been developed a model with three stages that solves the problem previously presented. It has also been developed a method to establish the needed steps to do an environmental efficiency evaluation of any existent equipment on the EA Technological layer.

This approach follows the principles related to the ABC [9] and the evaluation procedure of the Archimate [7].

To estimate the environmental efficiency a system load indicator is needed. This is the principle of this model. For example, the power usage of a computer can be estimated using its CPU usage rate as a load indicator. This principle relies on the research hypotheses number 2.

The following chapter (4.1) presents the Model early introduced and its three stages:

- Enterprise Architecture (4.1.1);
- Environmental Efficiency Accounting (4.1.2);
- IT Optimization Technologies (4.1.3).

Related to the principle previously described and developed to help on the validation of the model on a real environment with servers and computers, it is shortly presented an Energy Consumption Estimation Framework in the Accounting Stage chapter.

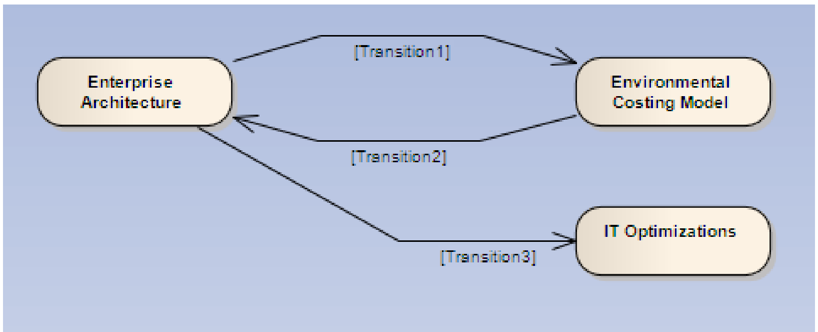

Figure 1. Environmental Efficiency Evaluation Model

4.1 Environmental Performance Evaluation Model

Figure 1 presents an Activity Diagram that explains the generic approach adopted to build this model.

This model consists in four steps divided through three stages.

First, describe the present situation on an EA model (see 4.1.1). This initial stage gathers the information needed to proceed with the Accounting Stage. Then the environmental efficiency of the architecture is estimated using the approach described in chapter 4.1.2.

With the efficiency figures in hand the EA is revisited and the model fulfilled with the estimation results (see 4.1.1). This representation helps the benchmarking of the architecture and the identification of environmental efficiency problems.

Finally there are some IT Techniques and Technologies that can be applied to the architecture to improve its eco-efficiency (see 4.1.3).

4.1.1 Enterprise Architecture Stage

This stage starts with the representation of the current situation using an EA model.

The artifact Device of Archimate Technological layer has been extended with a set of attributes allowing the modeling of the environmental related aspects. Figure 2 shows the formal representation of that Archimate extension.

The key attributes, relevant to the accounting stage, are those related to the energy consumption of the equipment and the associated usage rates of each operating stage.

The extension has been made only for two different kinds of equipments (computers and printers) because there is no scope in this work to cover all IT equipments. So it only focuses on the servers and computers which are the equipments with a larger footprint [2]. The printers are a possible case study.

The extension of this approach to other equipments relies on the identification of the load indicator for each one. This step is followed by the identification of each operation stage. For each operation stage an accounting of its usage rates and environmental footprint is required. Environmental footprint refers to power consumption or CO_2 emissions for example.

4.1.2 Accounting Stage

The accounting stage uses the information provided by the EA modeling to estimate the architecture environmental efficiency.

For each equipment described in the EA the accounting stage takes the usage rate of each operational stage and uses it to weight the energy consumption.

For example, consider the equipment Z spending 20% of the time at stage A and 80% at stage B. At stage A it consumes 1 unit of energy and at stage B 10 units of the same energy in a given timeframe. The accounting stage will estimate the energy consumption of the equipment as 8.2 units of energy per timeframe (0.2*1 + 0.8*10).

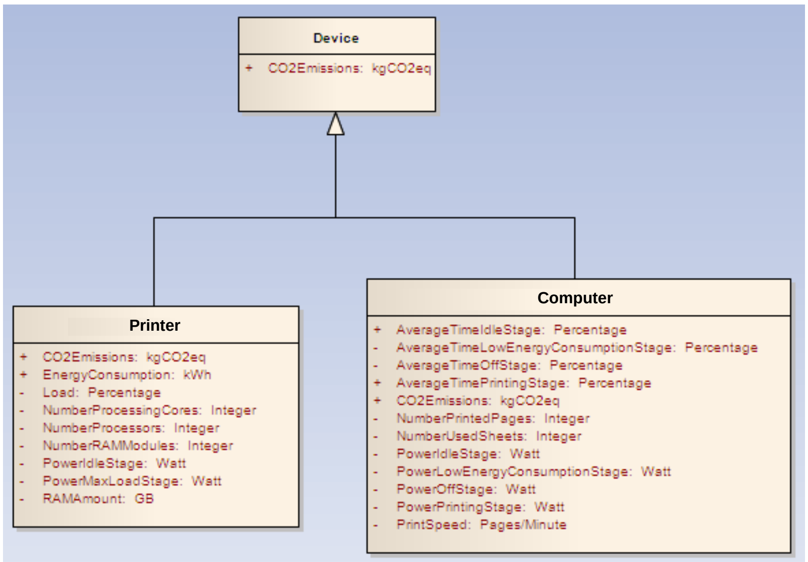

Figure 2. Archimate Extension

These figures are estimated for every equipment and then returned to the EA model.

After this step those figures can be arranged in multiple ways to proceed with a different analysis. For example using the EA these figures can be used to architecture benchmark or they can be geographically analyzed to help on find possible spots of environmental efficiency problems. These are just two possibilities.

Besides some state-of-the-art servers and manufacturers/assemblers provide installation equipment with power usage monitoring capabilities [22; 23] the load indicator chosen for the computers needs an independent framework to proceed with the power usage estimation of the equipment.

The operating stages of a processor can be discretized. But there's a trade off on that approach regarding the estimation accuracy and the number of added attributes to the artifact extension.

Taking into account that this framework isn't the focus of the research but, in other hand, it influences the usability of the proposed model, has been decided to develop a simple framework for server power usage consumption estimation.

This framework follows the principle of a load indicator to help on the environmental efficiency estimation that has been previously described. But in this case has been adopted an approach that only considers two stages of operation: idle stage and full load stage, relying in the case of 0% of CPU usage and 100% of CPU usage, respectively.

Between these two stages the power consumption is linearly estimated according to the CPU load growth.

The results of the theoretical proof of this approach leads to the results of a 3.25% average error. For further details about this framework see [24].

4.1.3 IT Optimization Technologies

Concluded the accounting stage and the results returning to the EA model, an analysis to the architecture environmental efficiency problems was made as described in chapter 4.1.2.

After that step there are techniques and technologies available that can be applied to the architecture to improve its environmental efficiency performance.

Some of the most recent technologies and techniques available are briefly described in chapter 2.3.

There are more opportunities of improvement but there is no scope in this work for an exhaustive identification and prioritization of all technologies available in the market. Instead, the choice made was to identify the some of the techniques and technologies available nowadays that allows the improvement of the IT environmental efficiency.

4.2 Environmental Evaluation Methodology

A methodology to help on with the execution of the case studies described below has also been developed using the model previously described.

This methodology is like a guide to assess the environmental performance of the IT equipments considered in this work.

The methodology consists in four steps (see Figure 3):

- **Define Performance Indicators**
  Definition of the system load indicator to estimate the environmental operation cost. Calculate the typical system usage rate. Identify the typical energy consumption for each usage level considered. This analysis is made using the enterprise architecture modeling capabilities described above in chapters 2.1 and 4.1.1.
- **Environmental Performance Evaluation**
  Assessment of the environmental cost of operation;
- **Results Presentation**
  Graphical or analytical representation of the achieved results to help on the identification of environmental efficiency problems;
- **Infra-structure Optimization**
  Identify and implement possible environmental enhancements to the infra-structure.

This methodology has been developed according to the environmental performance evaluation model (4.1) and has its foundations in the data provided by SPEC [25] about their evaluation procedures and the principles of ABC [26] and Archimate [7] charging models.

The following case studies will be used to validate the practical application of this suggested methodology.

5 Validation and Case Studies

The theoretical studies and practical assignments described below assists on the evaluation and validation of each component of the previously proposed model and methodology.

The chapter 5.1 describes the theoretical validation of the energy consumption estimation model. This chapter is followed by the computers case study, used to evaluate the application of the model and the methodology in a real situation to compare two possible scenarios (chapter 5.2).

The chapter 5.3 describes the application of the model and methodology on the printer's case study. Finally, the chapter 5.4 presents the conclusions of these three practical assignments.

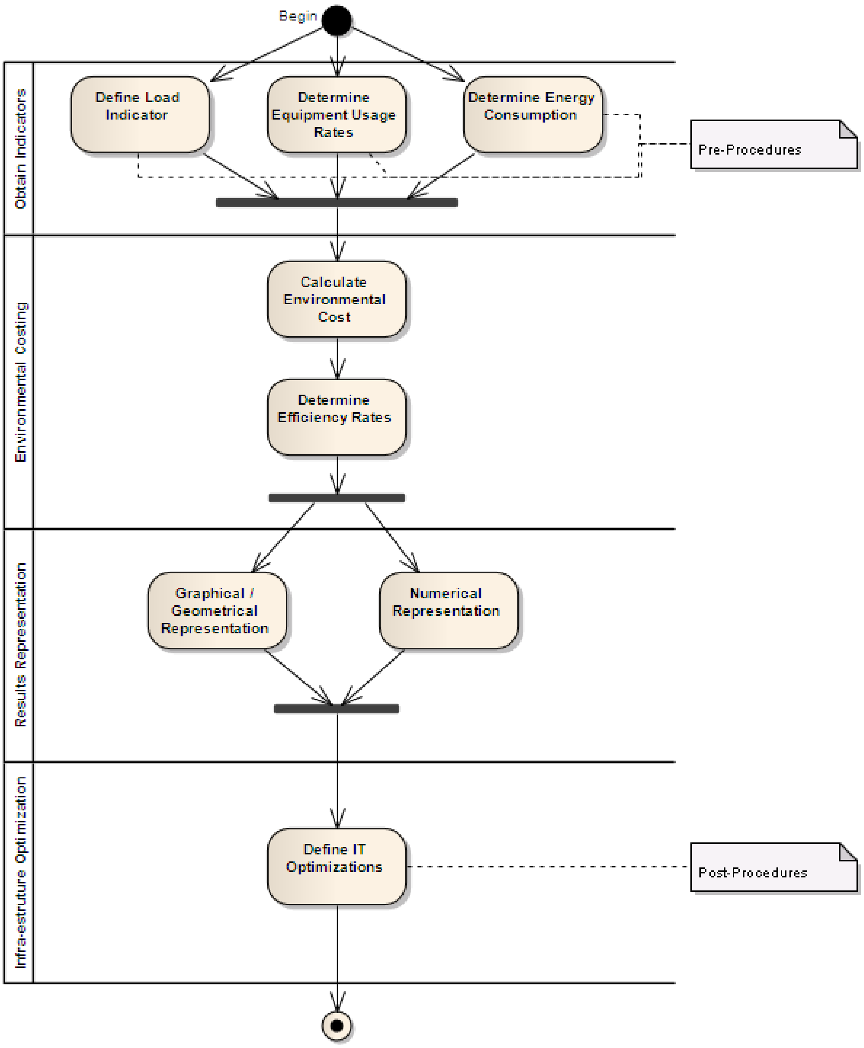

Figure 3. Representation of the Environmental Efficiency Evaluation Methodology

5.1 Validation of the Energy Consumption Estimation Model

To evaluate the practical application of the previously described model and methodology has been considered the realization of an assessment with computer servers. The problem regarding this case study is that it isn't possible to obtain in real time the power usage of the evaluated servers.

To do that a model has been developed to allow the estimation of the power usage of each server. That experiment is described in detail in this article [24].

The followed approach uses a model that estimates the server power usage according to a linear growth of the energy consumption between the lower and higher CPU usage ratios.

Theoretically, this approach leads to an average error result of 3.25%.

The framework developed to estimate the values of power usage in top and bottom CPU usage ratios leads to a rise in the error ratio to values of about 30%.

5.2 Computers Case Study

Two case studies have been developed to proceed with the validation of the model and methodology of environmental efficiency evaluation and the server's model power consumption estimation.

The first of them is the validation of the server's power usage estimation model with real computers.

The tests performed use a power meter device to determine the server's power consumption in real time. This power meter device was placed between the outlet and the server power cord. When the server had redundant power supplies, in order to avoid power balancing only one of them was kept operational.

Each power usage test consists in stabilizing the CPU load at a given level and then logs the CPU load and the power usage during 2 minutes.

These tests were run in three CPU levels:

- Full load (100%);
- Standard load (60%-40%);
- Idle load (0%).

Due to the difficulty in obtaining available server's to evaluate the model, it was only possible to complete two evaluations.

Both evaluations got results in line with the theoretical analysis previously made. This fact shows that the approach and principles of the model are correct.

To extend this evaluation, the performance and applicability of the model has been tested with personal computers (laptops and desktops).

The same tests described before have been applied to a set of 2 laptops and 2 desktops. But the practical results were far from the theoretical tests made with the server's.

The average error stands to 25% in laptops and 5% in desktops. However if the same framework was used to estimate the top and bottom power usage values, the average error rise up to 45% in desktops and 200% in laptops!

The average error of the estimation model on servers and desktops is very similar due to the identical tower form and power supply requirements. The increase of the model average error on laptops is related to the lower power requirements of the system and its different packaging form.

Finally, has been set up a simple case study to apply the model and methodology to compare the environmental efficiency in two different scenarios.

Each scenario consists of a computer that has to perform a test. The test is a mathematical challenge and the most efficient scenario is the one which completes its tasks with less energy consumed.

Scenario 1 contains a computer with a dual-core CPU architecture and Scenario 2 a computer with a single-core CPU architecture.

The defined power indicator was the CPU load. In Figure 4 are represented, using Archimate, the power consumption and CPU average load for each scenario.

The results of the test are synthesized in .

This comparison shows that a computer, even consuming more energy at top and bottom CPU load stages, can complete his job faster and also consume less energy, if can take advantage from its superior processing performance. These results only are valid if the tasks could be parallelized.

The accomplishment of this case study also demonstrated that the model and methodology for environmental efficiency evaluation can be applied with success to computers.

5.3 Printers Case Study

This methodology aims to be applied on every IT equipment. But, IT equipments are not only servers. To help on the validation of the model and methodology principles, a validation using a broader kind of equipments is essential.

The operation stages of a printer are well defined and his environmental efficiency is not only reliant on the power usage consumption. This makes this equipment behaves in a different way from the computers. This situation can potentially threat the principles behind the model and methodology design.

This case study has been developed in the Lisbon office of Deloitte. It has been used real data about all the printing jobs requested by Deloitte’s staff in Lisbon during 7 months.

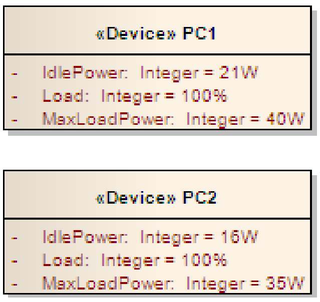

Figure 4. Scenarios Representation

Table 1. Environmental Evaluation Results

Scenario Identification	Environmental Cost (kWh)
Scenario 1	$1{,}11\text{x}10^{-3}$
Scenario 2	$3{,}53\text{x}10^{-4}$

Table 2. Printers Scenarios

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Centralized	No	No	Partially	Yes
Printing Centers / Floor	-	-	2	2
Number of Printers	62	50	35	13
Duplex Printing	No	Yes	Yes	Yes
Paper usage reduction (estim.)	0%	17%	25%	40%

For the environmental efficiency performance comparison has been considered 4 different scenarios. Those scenarios are synthesized in Table 2.

The Scenario 1 and 2 are real situations. The Scenarios 3 and 4 have been designed to evaluate the environmental performance of printers in a centralized situation.

Duplex printing is related to the printer standard configuration to print on the sheet both sides. Paper usage reduction is an estimated factor of paper reduction due to the reduction of printing jobs across the office regarding the distance of the printing centers to the open space work seats, for example.

The methodology indicates the need to define an indicator to estimate the environmental cost. In this case, the factor that most influences the eco-footprint of a printer is the print job. The more you print the greater is the eco-footprint. So the indicator considered is the average number of sheets printed in a time frame.

Has been measured the print speed of each existing printer model in the office. The power consumption values considered were those published in the printer's data sheets.

The environmental costing was made in 5 steps:

- For each printer, was gathered information about the number of printing jobs done on each month;
- For each month, was calculated the average time that each printer spends on each operation state (Printing, Idle, Sleep, Off);
- For each month, was calculated an weighted average of the printer energy consumption for the time spent on each operation state;
- For each month, was calculated the footprint of the paper used by each printer;
- For each printer on each month, was added the footprint of the estimated energy consumed to the footprint of the used paper.

At the end have been established 3 environmental efficiency levels to rank each printer performance. With this ratios and applying this costing method for each scenario considered, the comparison of the environmental efficiency of each scenario has been possible.

The successfully completion of this case study shows that the model and methodology defined above are adequate to be used with this type of equipments.

The results achieved show that that the most efficient solutions are the scenarios 3 and 4. Those results demonstrate that the centralized approach is the most environmental and cost efficient solution.

Another important observation is that the most efficient approach is the one that use printers with a lower power usage at the Idle state. The printers spend the most part of the time in that operational state, so the biggest power usage fraction comes from this state. This was one of the problems identified in Scenarios 1 and 2.

Those remarks were used internally by Deloitte to evaluate the change of their printing architecture to one more eco-friendly and cost effective.

5.4 General Discussion of Achieved Results

The models and methodology proposed and the results of the case studies realized, shows that the previously formed research hypotheses (see chapter 3.1) are true.

For the Hypothesis 1, the model for environmental efficiency evaluation considers the step of Enterprise Architecture stage (see chapter 4.1.1).

For the Hypothesis 2, the server power usage estimation model (see 5.1) and the printers case study (see 5.3) shows that this environmental accounting can be made.

For the Hypothesis 3, the printer's (5.3) and computer's (5.2) case studies shows that the proposed models and methodology are capable of scenario comparison analysis and allows the identification of environmental efficiency problems.

Finally, for the Hypothesis 4 the research made on the chapter 4.1.3 shows that exists techniques and technologies available to solve or reduce the impact of the environmental problems identified on the evaluated scenarios.

6 Conclusions

As previously said (see 1) the interest in this research area is growing especially because the practical application in companies because of the savings it allows.

Considering that, this work fits in a highly interesting area, full of potential to expand and develop possibilities to meet the industry concerns.

The results achieved show that the proposed solution solves the defined problem. Among the various components of this work there are some that are more relevant than others. To split them, the final conclusions of this work are divided into major (6.1) and minor contributions (6.2). Finally some development lines regarding this work (6.3) have been established.

6.1 Major Contributions

The major contributions of this work are:

- **Methodology for environmental IT efficiency evaluation**. Establishes a process to guide an environmental efficiency evaluation to the IT, helping decision making related to changes made on this organizational layer.
- **Enterprise architecture extension to model environmental aspects in the Infra-structure layer.** This contribution inserts the solution into a context whose importance and awareness has been growing in companies worldwide. This also lets the solution to be extended through all of the others enterprise layers, carrying the environmental costing across the organizations.
- **Servers power consumption estimation model.** Even not being the main focus of this work, this solution component is based on a simple principle and purposes are a simple approach to estimate the server eco-footprint with an acceptable average error.

6.2 Minor Contributions

The minor contributions of this work are:

- **Applying the methodology of IT environmental evaluation in enterprise context.** The case study that Deloitte accepted allows the validation of the methodology purposed in a real context.
- **Practical validation of the power consumption estimation model to personal computers.** Using the same approach of the model used to estimate the power usage in server's tests to personal computers were done in order to evaluate the performance of the model principles in more compact systems and with different energy and thermal requirements.

6.3 Future Work

Gathering all the limitations and looking to all the open possibilities of this work, there are some improvements that can be made in line with this work:

- **Validate the methodology application against a larger set of IT equipments.** Validate the principles and the approach of the proposed methodology to be applied to all IT equipments.
- **Extend the environmental model and methodology approach to the upper levels of the enterprise architecture.** Using the same principles and approach used to the infrastructure layer, extend the approach to all the other layers and extend the environmental concerns and cost accounting through the organization.
- **Add to the cost accounting model other costing dimensions.** Extend the approach adopted on the model and methodology to gather information related to other relevant equipment costs like investment, disposal or operation costs regarding persons and maintenance procedures. This will allow the comparison between the life cycle costs to implement one of several possible enterprise architectures.

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