Ronald Brisebois[1], Apollinaire Nadembega[2], Alain Abran[3]

Real Time Software Energy Consumption Measurement in the Context of Green Software

Abstract

Software energy consumption has become an environmental challenge that Software Engineering (SE) needs to consider. From the perspective that the end user should be able to monitor the software energy consumption during its use, we propose a set of measures and indicators to evaluate the energy consumption of a software search engine, software search results display, a user interface and a user workflow. We also propose a dashboard and visual indicators to allow users to monitor, in real time, the green index of software during its use.

Keywords: real-time indicator, green index, measurement, energy efficiency, smart library, green ICT, green software, software metrics, user interest, smart city

1. Introduction

Energy efficiency is finally becoming a mainstream goal in a world where consumption of resources cannot grow forever. Indeed, a 2012 environmental data investigation indicated that global carbon dioxide emissions had reached 9.1 billion tons, the highest level in human history and 49 percent higher than in 1990[4]. Software Engineering (SE) is also impacted: the rapid growth and significant development of Information and Communications Technology (ICT) systems are beginning to cause an increase in worldwide energy consumption. This issue is leading technology producers, information systems managers, and

---

[1] Bibliomondo, 7695, av. Papineau Montréal, Québec, Canada, ronald.brisebois@bibliomondo.com.com

[2] Bibliomondo, 7695, av. Papineau Montréal, Québec, Canada, apollinaire.nadembega@bibliomondo.com.com

[3] École de Technologie Supérieure, Université du Québec, Canada, alain.abran@etsmtl.ca

[4] G.P. Peters et al., *Rapid Growth in CO2 Emissions after the 2008–2009 Global Financial Crisis*, "Nature Climate Change" 2012, vol. 2, pp. 2–4.

researchers to become involved in reduction of energy consumption. While research has increasingly focused on improving the energy efficiency of hardware[5], there is a scarcity of research for accurately quantifying the energy impact of software. Although software systems do not consume energy directly, they affect hardware utilization, leading to indirect energy consumption. It is important for software engineers to take into account the optimization of energy consumption when designing and implementing a software system. Reducing the energy consumption and related carbon dioxide emission of ICT systems is thus an important issue and has justified the emergence of the concept "green ICT"[6]. Green ICT is defined as the study and practice of using computing resources efficiently to reduce negative impacts on the environment[7]. Recently, the ICT system industry and academia have started working to make software greener[8]. But to do so, indicators for measuring green indexes are needed. Unfortunately, most of the effort of greening ICT systems has been focused on developing dynamic resource provisioning and allocation algorithms that consider the synergy between various data center infrastructures (i.e., the hardware, power units, and cooling) and that work holistically to boost data center energy

---

[5] L. Ardito et al., *Introducing Energy Efficiency into SQALE*, 3rd International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies, Lisbon 2013.

[6] S.L. Slocum, S. Lee, *Green ICT Practices in Event Management: Case Study Approach to Examine Motivation, Management and Fiscal Return on Investment*, "Information Technology & Tourism" 2014, vol. 14, no. 4, pp. 347–362; S. Taruna, P. Singh, S. Joshi, *Green Computing in Developed and Developing Countries*, "International Journal in Foundations of Computer Science & Technology (IJFCST)" 2014, vol. 4, no. 3, pp. 97–102; B. Ayse Basar, M. Maurizio, M. Andriy, *Green Software*, "IEEE Software" 2014, vol. 31, no. 3; A. Raturi, B. Tomlinson, D. Richardson, *Green Software Engineering Environments*, in: *Green in Software Engineering*, ISBN 978–3-319-08580–7, 2015, pp. 31–59; Z. Gandomi, S.B. Amin, *Towards Green Computing Application for Measuring the Sustainability of Data Centers: An Analytical Survey*, International Conference on Electrical, Electronics, Computer Engineering and their Applications, Kuala Lumpur, Malaysia 2014; S. Agarwal, S. Chakrabarty, A. Bhaumik, A. Nath, *Trends and Awareness in Green Computing Initiatives: A Comprehensive Study*, "International Journal of Advance Research in Computer Science and Management Studies" 2015, vol. 3, no. 4; A. Buchalcevova, *Green ICT Maturity Model for Czech SMEs*, "Journal of Systems Integration" 2015, vol. 6, no. 1.

[7] A.M.H. Abdallah, M. Hazura, M.J. Hairulliza, *The Adoption of Green ICT Practices as a Driver in Supply Chain Management*, "International Journal of Digital Content Technology and its Applications" 2014, vol. 8, no. 6.

[8] R. Hegade, V.R. Patil, *Green Cloud Computing*, "International Journal of Scientific Engineering and Technology Research" 2015, vol. 4, no. 3; J.-C. Deprez, C. Ponsard, *Energy Related Goals and Questions for Cloud Services*, First International Workshop on MeGSuS 2014; C. Calero, *A General Overview of Software Sustainability Measurement*, First International Workshop on MeGSuS'14, Rotterdam 2014.

efficiency and performance[9]. In order to overcome the gap between the data center industry and the software industry in regard to green ICT challenges, researchers in the software field are focusing their work on green indicators for software. It is essential to have precise figures of the current energy consumption of software in order to understand how to reduce power consumption and design future energy-efficient software. Unfortunately, the existing green indicators do not allow monitoring by the end user.

To resolve this issue, this paper proposes:

(1) a set of measures and indicators to evaluate energy consumption for important software tasks such as: search engine computation, search results display, user interface, and workflow,

(2) a new algorithm to compute, monitor and control in real time, according to user interest, a software green index, called BIBLIOMONDO Software Green Index (BMSGI); BMSGI is based on our green indicators and allows the end-user to answer the question: Is this software green?, and

(3) a dashboard, called BIBLIOMONDO Green Indicator Dashboard (BMGID), to visualize, in real time or in a reporting mode, our green indicators and BMSGI.

In the context of global warming, the potential benefit of this approach is to make software users aware of their involvement in the degradation of the ozone layer: this will allow these users to make useful decisions for our planet in terms of energy consumption. However, the reduction of energy consumption proposed in this paper has an impact on the application interface; that is a limitation for users.

The remainder of the paper is organized as follows: Section II presents related works, Section III describes the energy measurement and real-time monitoring of our green indicators, Section IV presents a summary and some avenues for future research.

2. Related Work

With the focus on resource constraints in ICT systems, research is being conducted in the area of energy-efficient computing and green software measurement. For example, there is related work on measuring data center and cloud-related

---

[9] Ibidem.

energy consumption[10]. However, less importance has been given to the role of software in the energy-efficient use of hardware[11]. In *Energy Related Goals and Questions for Cloud Services*, the authors proposed a framework to assist cloud application developers to learn how much energy is consumed by their application on the server side. However, no real-time indicator was proposed, either through a dashboard or an icon within the application itself, to highlight the effort of developers to provide green software applications. In addition, the KPI were limited to the server-site components. In *A General Overview of Software Sustainability Measurement*, the authors attempt to clarify the different aspects of software sustainability, in addition to how they are measured and by whom. Their intent was not to provide a detailed guide to the work developed in the area but rather a snapshot of what is important in the area of software sustainability measurement. They defined three dimensions of software sustainability: software social sustainability, software economic sustainability and software greenability. However, they did not provide a formula to compute the green indicators for this third dimension.

In summary, the main limitation of these related works was the focus on software development with related examples. The proposal presented did not illustrate a real-time dashboard with visual indicators that presented users with the greenability of the provided software: that task remained to be tackled.

There is a scarcity of related works on this specific topic: we have not found any proposal in the literature addressing the software energy consumption in a similar way.

3. Energy Measurement and BMGID

Sub-section 3.1 presents the set of measures and indicators proposed to compute the software greenability. Sub-section 3.2 presents the dashboard designed to report the computed green indicators.

---

[10] R. Hegade, V.R. Patil, *Green Cloud Computing*, "International Journal of Scientific Engineering and Technology Research" 2015, vol. 4, no. 3.

[11] J.-C. Deprez, C. Ponsard, *Energy Related Goals and Questions for Cloud Services*, First International Workshop on MeGSuS 2014; C. Calero, *A General Overview of Software Sustainability Measurement*, First International Workshop on MeGSuS'14, Rotterdam 2014.

3.1 Energy Measurement Indicators

This paper proposes four green indicators to calculate the green index of a software system. These indicators are those most important in the context of library management software and other similar ICT systems for cities, whether in the cloud or not. Several cities have cultural centers that offer services similar to libraries.

3.1.1 Search Engine Energy Consumption Indicator (SEe)

This section describes the energy consumption evaluation for a search engine (*SEe*). Note that energy consumption depends on an individual computer with its specific components where α (in watts *[W]*: 1 watt is equal to 1 joule per second) denotes the maximum consumption of all computer components (CPU, RAM, CPU fan, communication buses). The formula for this green indicator is as follows:

$$SEe = \alpha + \sum_{i=1}^{n} \left(\frac{Ei}{\beta i} \right) + \sum_{j=1}^{m} Cj + \sum_{f=1}^{t} Qf \qquad (1)$$

where
βi = the execution time (in seconds) of function i used by the search engine,
Ei = the energy cost (in joules*)* of a function i,
n = the number of functions called by the search engine *SE*,
Cj = the energy consumption (in watts [W]) of external functions,
m = the number of external functions. An external function is one in which the source code is not written by our developers; for example, a remote request where the process is run on a remote computer. This energy consumption needs to be added to the overall energy consumption of the search engine,
Qf = the energy consumption (in watts) of an f^{th} occurrence of a search textbox autocomplete entry,
t = the number of occurrences of a search textbox autocomplete entry.
α = a predefined parameter that can be determined by measurement. For example, desktop computers with Intel Pentium 3 CPUs averaged 38W when on, compared to an average of 67W for desktop computers with Intel Pentium 4 CPUs, and an average of 104W for desktop computers with AMD Athlon CPUs.

3.1.2 Search Results Display Energy Consumption Indicator (SRe)

This section describes the energy consumption for search results display (*SRe*). Note that each type of display screen has a different energy consumption. The formula for this green indicator is as follows:

$$SRe = \varepsilon + \sum_{l=1}^{z} \left(\frac{Pl}{\omega l} \right) \tag{2}$$

where

ε (in watts [W]) denotes the maximum energy consumption of the monitor. For example, the average LCD monitor uses 15W in active mode, 1.5W in low-power mode and 0.5W when turned off, while a CRT monitor uses 100W in active mode, 9.5W in low-power mode and 2.5W when turned off.

ωl = the display time (in seconds) of a component l in the current result page of the search results,

Pl = the energy cost (in joules) of a component l,

z = the number of components displayed on the results page.

3.1.3 User Interface Energy Consumption Indicator (UIe)

This section describes the energy consumption evaluation for a user interface (*UIe*). As in *SRe*, each type of screen has a different energy consumption; ε is also used to compute *UIe*. The formula for this green indicator is as follows:

$$UIe = \varepsilon + \sum_{h=1}^{x} \left(\frac{Uh}{\omega h} \right) \tag{3}$$

where

ωh = the display time (in seconds) of a component h on the search results page,

Uh = the energy cost (in joule*s)* of a component h,

x = the number of components displayed on the results page.

3.1.4 Workflow Energy Consumption Indicator (We)

This section describes the energy consumption evaluation for a user workflow (*We*). As in *SEe*, α is also used to compute *We*. The formula for this green indicator is as follows:

$$We = \alpha + \sum_{g=1}^{y}\left(\frac{Rg}{\beta g}\right) \tag{4}$$

where
βg = the execution time (in seconds) of step g of the workflow,
Rg = the energy cost (in joules) of step g of the workflow,
y = the number of steps in the workflow.

3.1.5 BIBLIOMONDO Software Green Index – BMSGI

This section describes the BIBLIOMONDO Software Green Index (BMSGI), designed to notify the end-user that he/she is using green software. BMSGI is computed as follows:

$$BMSGI = \sum_{k=1}^{s}(\Omega k \times ECk) \tag{5}$$

where
ECk = EC (Energy consumption), with the indicator k to take into account more than our four defined indicators (SEe, SRe, UIe and We),
Ωk = the weight of indicator k, and

$$\sum_{k=1}^{s}(\Omega k) = 1$$

Note that Ωk is used as a weight for ECk; this mechanism assigns weight to each indicator according to the software profile. For example, in the software where workflows are commonly used by end-users, as opposed to other types of process, the assigned weight Ωk of indicator k *We* must be greater than the other indicator weights:
s = the number of indicators taken into account for the BMSGI computation.

To set the different levels of software greenability, EC1 and EC2 are defined as the boundary energy consumption values between:

(i) low energy consumption: Low BMSGI (BMSGI ≤ EC1),
(ii) medium energy consumption: Medium BMSGI (EC1 < BMSGI < EC2), and
(iii) high energy consumption: High BMSGI (BMSGI ≥ EC2).

Fig. 1 shows the BMSGI real-time visibility: one of these icons appears on the corner of the screen (see Fig. 2) to indicate the BMSGI level of the current page.

Figure 1. Illustration of BMSGI Real-time Visibility

Source: the authors' own work.

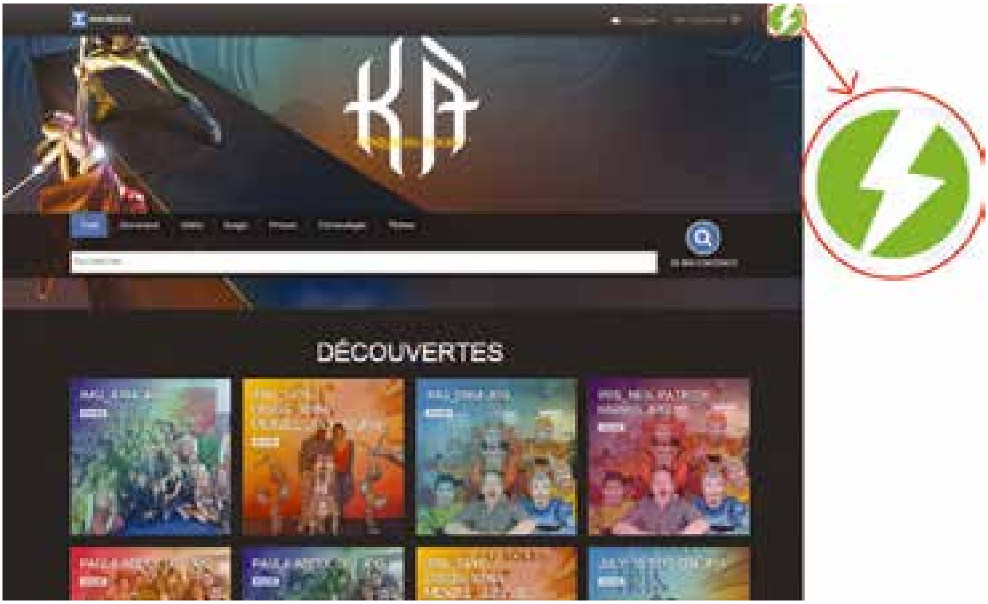

Figure 2. InMédia Suite BMSGI Illustration

Source: the authors' own work.

3.2 Green Indicators Dashboard

The BIBLIOMONDO Green Indicator Dashboard (BMGID) (see Fig. 3) is a specific section of the Smart Library project of BIBLIOMONDO that provides a real time indicator of the business process and data.

Figure 3. Dashboard of Real-time Indicator Monitoring

Source: the authors' own work.

4. Summary

In this paper, we presented the green indicators used in our BMSGI algorithm to identify a software green index. More specifically, we proposed, first, the measures and indicators to evaluate the energy consumption of important software aspects, including: search engine computation, search results display, user interface, and workflow. Next, based on these indicators, we computed the BMSGI algorithm and proposed a green indicator dashboard called BMGID for viewing the algorithm both in real-time and in a reporting mode. In practice, users can download, install and set up our BMSGI and BMGID. These two schemes will be integrated to their browser and will collect data to display the web applications energy consumption. In future work, we will propose a library self-service checkout terminal with green hardware and software; the objective is to reduce cataloging time and workflow steps when items are borrowed or returned.

References

Abdallah A.M.H., Hazura M., Hairulliza M.J., *The Adoption of Green ICT Practices as a Driver in Supply Chain Management*, “International Journal of Digital Content Technology and its Applications” 2014, vol. 8, no. 6.

Agarwal S., Chakrabarty S., Bhaumik A., Nath A., *Trends and Awareness in Green Computing Initiatives: A Comprehensive Study*, “International Journal of Advance Research in Computer Science and Management Studies” 2015, vol. 3, no. 4.

Ardito L., et al., *Introducing Energy Efficiency into SQALE*, 3rd International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies, Lisbon 2013.

Ayse Basar B., Maurizio M., Andriy M., *Green Software*, “IEEE Software” 2014, vol. 31, no. 3.

Buchalcevova A., *Green ICT Maturity Model for Czech SMEs*, “Journal of Systems Integration” 2015, vol. 6, no. 1.

Calero C., *A General Overview of Software Sustainability Measurement*, First International Workshop on MeGSuS’14, Rotterdam 2014.

Deprez J.-C., Ponsard C., *Energy Related Goals and Questions for Cloud Services*, First International Workshop on MeGSuS 2014.

Gandomi Z., Amin S.B., *Towards Green Computing Application for Measuring the Sustainability of Data Centers: An Analytical Survey*, International Conference on Electrical, Electronics, Computer Engineering and their Applications, Kuala Lumpur, Malaysia 2014.

Hegade R., Patil V.R., *Green Cloud Computing*, “International Journal of Scientific Engineering and Technology Research” 2015, vol. 4, no. 3.

Peters G.P., et al., *Rapid Growth in CO2 Emissions after the 2008–2009 Global Financial Crisis*, “Nature Climate Change” 2012, vol. 2, pp. 2–4.

Raturi A., Tomlinson B., Richardson D., *Green Software Engineering Environments*, in: *Green in Software Engineering*, ISBN 978–3-319-08580–7, 2015, pp. 31–59.

Slocum S.L., Lee S., *Green ICT Practices in Event Management: Case Study Approach to Examine Motivation, Management and Fiscal Return on Investment*, “Information Technology & Tourism” 2014, vol. 14, no. 4, pp. 347–362.

Taruna S., Singh P., Joshi S., *Green Computing in Developed and Developing Countries*, “International Journal in Foundations of Computer Science & Technology (IJFCST)” 2014, vol. 4, no. 3, pp. 97–102.