

Economic Aspects of Green ICT

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Abstract Environmental concerns increasingly become a priority and a global issue. In spite of that, the major incentive for a company to go green is reducing costs and increase revenues. While green ICT practices mostly focus on environmental and technical issues, they barely address the implicit economic impact that they may have. This aspect is critical in the decision-making process for many researchers and practitioners that need to estimate upfront the financial impact of applying a practice. As a consequence, we believe users can minimize these issues by using the following two approaches: (i) a green model to visualize the business value exchanged between enterprises and end-users when applying a green strategy; and (ii) a system to calculate the cost savings that would be obtained when applying a green practice on a pre-existing ICT solution. In this chapter, we propose using the e^3 value technique to model and perform trade-off analysis among alternative green practices, particularly from an economic perspective. Moreover, we have designed and implemented a Web-based software tool that enables to analyze and calculate the direct and indirect economic impact of a practice before it is adopted in production. These two approaches are the first step towards calculating how much green ICT costs, and motivating organizations to reuse green ICT solutions based on informed decisions.

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1 Introduction

Over the last decades, the use of Information and Communication Technology (ICT) and software systems has exploded, making our lives and work much more efficient. However, besides the benefits that ICT brings us, it also contributes significantly to environmental issues [13][11], not only because of the electricity consumed by computers, data centers, networks or other ICT utilities, but also due to the rapidly growing computation needs of emerging software systems that contribute significantly to ever increasing energy demands and greenhouse gas emissions [21][1]. Decreasing ICT operation expenses becomes more and more crucial. How to make ICT greener (i.e. environmentally sustainable) and how to develop greener software has been gaining significant attention [17][16][24].

ICT can contribute to addressing environmental concerns in two ways, (1) by optimizing the implementation of ICT or migrating to sustainable software and thus minimizing its own environmental impact, and (2) by optimizing the business processes via more environmental sustainable software and thus minimizing the use of ICT resources [5, 22]. Currently, many green ICT practices already exist to improve the energy efficiency of both IT and its supported processes. Examples include reducing the energy consumption of PCs by enabling power management features [20], enforcing double-sided printing to save both paper and energy [18], applying cloud computing technology to significantly reduce hardware and software resources needed for individuals [15], and using a fleet management system and dynamic routing of vehicles to avoid traffic congestion and thus minimize energy consumption and transportation costs [2].

From the examples above we can see that greening ICT may save energy consumption (hence reducing cost) but it often requires additional investments, business process changes, and extra efforts from both companies and individuals. According to the analysis by Corbett [4], the most commonly cited driver for reusing green IT practices is saving costs. Especially in times of economic crisis, cost reduction becomes the most important economic objective [23] of many companies. If green practices do not lead to an explicit (and significant) reduction of costs, environmental goals are often regarded as a nice optional bonus rather than a must-have target.

There is no one-size-fits-all green solution due to the diversity of requirements and characteristics of these enterprises. Executives need to assess the effectiveness of green ICT practices not only from a technical perspective but more importantly from an economic point of view, and not only look into short-term return on investments (ROIs) but also have a vision on long-term ones. In addition, when green ICT practices involve software, calculating costs and ROIs is more difficult. The impact of software cannot be estimated in isolation, as it depends on many indirect factors including operation costs, hardware usage, human involvement, and system configuration. Often there is an intuition of some advantage gained when investing in such practices. This intuition is sufficient only if the company and decision makers are already fully committed to re-greening their software and ICT portfolio. In most cases evidence and quantification is the only way to handle the complexity of the practices mentioned above, and hence to create such commitment.

To ensure economic benefits while making a sustainable business, there must be an alignment between green goals and organizational/business goals. Only when such an alignment is in place, the decision makers of a company can be motivated to take green actions [14]. In the business domain, the strategy modeling language (SML) [19] has been used to align business model with business goal, business plan, and optimization objectives to ensure business strategies can be optimally realized. However, a systematic approach is needed to describe solutions, actions or strategies that can produce environmental benefits and enforce the alignment between green strategies and business goals [8].

Moreover, there is a need for quantifying in advance the economic impact of green practices. To the best of our knowledge, there is a software tool, named Going Green Impact Tool¹, that compares the economic value among multiple green practices specifically for data centers. This tool provides a very comprehensive analysis on the key environmental and economic consequences of the application of certain green practices, which aids executives to determine the most effective practice. The major limitation of this tool lies in the fact that it works only for pre-defined practices, including: server optimization, power management, virtualization, free cooling and the re-use of waste heat. End-users are not able to add other solutions for analysis and comparison.

Consequently, to our knowledge there is no single tool that is able to aid decision makers to run a holistic assessment and make informed decisions. In this chapter, we present a green model and software tool that allow us to model, estimate, quantify and compare the economic consequences of the application of green practices. To do that, we used the *e³value* model, which is a economic tool to model business networks and has been successfully applied in several real life business case studies [7]. We designed and implemented a Web-based software tool that enables to analyze and compare the economic impact of applying a green practice versus an existing ICT solution. To this end, we carried out an experiment of modeling a green ICT practice called “desktop virtualization”. The results show that by applying this practice a company would reduce overall expenses with 47% and reduce electricity consumption with 20%. This research combines formalized descriptions of green ICT practices with economic models estimating the business values of ICT solutions. By modeling the application of a green practice, we can customize the value exchanges to real scenarios and estimate the expected ROIs using our software tool.

The estimations above showed that while intuition was promising, the actual figures were delivering amazingly higher ROIs. We argue that such quantifications would convince organizations more easily to adopt green ICT practices, and motivate them to reuse green ICT solutions even if requiring significant investments. The remainder of the chapter is structured as follows. Section 2 introduces the *e³value* model; Section 3 presents our green strategy model; Section 4 shows an example on how to model a green ICT practice called *desktop virtualization*; Section 5 presents our Web-based software tool and an example using the *desktop virtualization* practice and Section 6 concludes the chapter.

¹ <http://ercim-news.ercim.eu/en79/special/the-going-green-impact-tool>

2 Background: The e^3 value Methodology

e^3 value models enterprises and end-users exchanging things of economic value, such as goods, services, and money, in return for other things of economic value. In the following, we introduce the main concepts or constructs supported by the e^3 value modeling tool and their associated notations [12][6].

- **Actor.** An economically, and often legally, independent entity. Examples of an actor include a customer, an organization and a company. In the notation, an actor is represented by a plain rectangle.
- **Value object.** Something that actors exchange which is of economic value for at least one actor. A value object is a service, a good, money, or an experience. Examples of value objects are products, delivery service and tuition fee. In the notation, a value object is represented as a label on a value exchanging.
- **Market segment.** A set of actors that share a set of properties. Actors in a market segment assign economic value to value object equally. In the notation, a market segment is represented by a set of stacked rectangles.
- **Value interface.** Something that group value ports together and show economic reciprocity. Economic reciprocity means that actors/market segment will only offer value objects if they will receive value objects in return. In the notation, the value interfaces are drawn at the sides of actor/market segments as a thin rectangle with rounded corners, with value interfaces within.
- **Value port.** Something that is used by an actor/market segment to provide or request a value object. In the notation, a value port is shown as a small arrow inside a value interface.
- **Value exchange.** Connect two value interfaces and represent a potential trade of value objects. In the notation, value exchanges are drawn as lines connecting the port of actors/market segment to each other.
- **Dependency path.** The path where value exchanges, which is used to count the number of exchanges. In the notation, dependency path starts with a start stimulus and ends with a stop stimulus.

As illustrated in Figure 3, many e^3 value constructs can be associated with numbers or parameters, such money transfers as well the number of consumer needs (here the need for concurrent computing). If done correctly, the e^3 value modeling tool generates net value flow sheets, which show for each actor in the model the amount flowing into and out from an actor.

3 Modeling the Value Exchange of Green ICT practices

The design of our green strategy model was inspired by the definitions collected by the Global Development Research Center (GDSC²), which is an independent non-

² www.gdrc.org

profit think tank carrying initiatives in education, research and practice. Their goal is to contribute to broad-based global development by facilitating the creation and use of knowledge. The GDSC glossary of environmental terms elicited definitions from international organizations (like ISO and the Environmental Protection Agency of the USA). We found two definitions especially relevant to our purposes:

- **Definition 1.** A **green strategy** (aka environmental strategy) is a plan of action intended to accomplish a specific environmental goal.
- **Definition 2.** A **green goal** (aka environmental goal) is an objective that an organization sets itself to achieve, and which is quantified where practical.

The first definition breaks down a strategy into two components: a plan of actions and a specific environmental goal the actions should help achieving. Moreover, the second definition implies that whenever applicable we should be able to quantify the extent to which an environmental goal is achieved. This calls, in our opinion, for the association of metrics (either qualitative or quantitative) that measure the contribution of each action to the achievement of the goal.

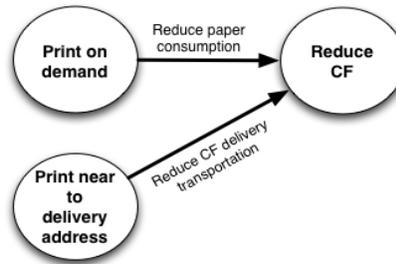


Fig. 1 Example: A green strategy for electronic bookstores.

Putting the above elements together, we designed the first version of a green strategy as graphically illustrated by the example in Figure 1. The example has been extracted from the electronic bookstore domain. It represents a strategy aiming at reducing the carbon footprint (CF) of printing books.

The strategy includes two actions: the first action *Print on demand* refers to printing books only after customers order them. This action makes the business more sustainable by reducing the costs of storing books in large quantities before customers order them. While this effect is not “green per se”, i.e. it does have an indirect positive impact on the total CF by reducing paper consumption to the minimum (i.e. exactly the amount of books that are actually ordered by customers). The second action *Print near to delivery address* is to physically print the ordered books in a store as near as possible to the address of the customer. This allows to shorten the delivery distance, hence reducing the CF of transportation. We developed a number of examples (from both theory and practice) to challenge our first model of green strategy. In doing that, we have identified the following weaknesses.

1. Each action can have one or more effects that help achieving the environmental goal. In order to select the best actions to put in place in a certain organization we must make each effect explicit. In doing that we can understand further what we need to measure to monitor the progress toward achieving the green goal. For instance, in the example of Figure 1 the action effects (added on the associated arrows) identify that by monitoring paper consumption and transportation distances, respectively, we can draw the trend toward reducing the total CF.
2. While action effects are typically technical or environmental in nature, they do not explain the economic impact that they have. We had various discussions with companies actively involved in green ICT and/or in decreasing their CF, and all explained that the major incentive for them to go green is to reduce costs. Hence, if green strategies do not lead to an explicit (and significant) reduction of costs (hence increase in revenues) they are (again) nice but not part of the business strategy of the organization. In periods of economic crisis, they are the first to be forgotten, or neglected.

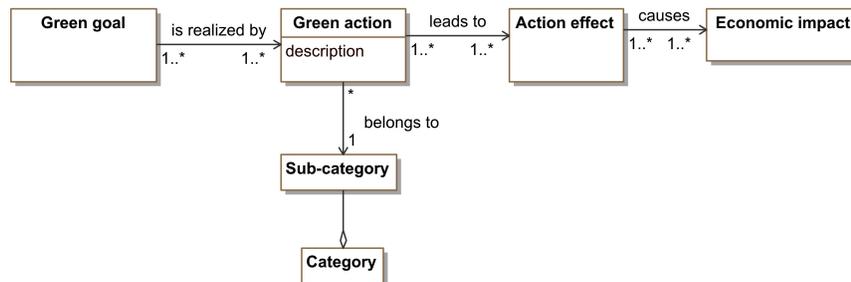


Fig. 2 Green strategy model.

To challenge our first model in aligning green strategies and business strategies, we associated each action effect with its (potential) economic impact. This resulted in the revised green strategy model illustrated in Figure 2. A green goal is realized by a number of green actions, and a green action can achieve a number of green goals. Each green action has a description to explain what the green action means. A green action leads to at least one action effect, which causes at least one economic impact. A green action belongs to one sub-category, which is a sub-set of a category. While the green goal represents ecologic impact of the strategy as a whole, the action effects detail the ecologic impact of each action individually.

4 Example of Modeling a Green ICT Practice

Aiming at assessing the feasibility of quantifying economic values of green ICT practices, we carried out an experiment by modeling the application of a practice called *desktop virtualization*, which has been selected from the list of green solutions provided by MJA (Meerjarenaafspraken meaning long-term agreements)³. This practice is described as:

A desktop virtualization software facilitates the use of thin clients (i.e. workstations with minimal hardware configurations). These thin clients are far more energy efficient than regular fat client computers. There is however an increase in server side computing due to the extra load of providing the desktops, which leads to an increase in energy consumption of servers.

From this description, we elicited the following expected effects and associated economic impact:

- *Decrease energy consumption of client workstations, which decreases energy consumption costs of client workstations.*
- *Increase energy consumption of servers, which increase energy consumption costs of servers.*
- *Acquisition of thin clients, which may rise IT equipment acquisition costs.*
- *Need to implement or purchase virtualization software, which requires short term investment.*

Using the e^3 value modeling tool, we modeled an AS-IS situation (i.e. usage of fat-client without virtualization) and TO-BE situation (i.e. usage of thin clients with virtualization) with the period of *three years*. Figure 3 shows the AS-IS situation, where company X purchases a number of fat-clients and servers from hardware suppliers in order to meet its computation needs, pays money to electricity suppliers for the electricity consumed by these fat clients and servers, and hosts an IT department (within the company or outsourced) to maintain the hardware devices ensuring they perform as expected. Figure 4 illustrates the TO-BE situation, where company X purchase thin clients rather than fat clients and the IT department has an additional task of providing and maintaining a virtualization software to deliver desktop virtualization service.

Value exchanges can be calculated along multiple dependence paths presented in the models. The paths start with the start stimulus 'Concurrent computing need' of Company X. Such need can be fulfilled by a combination of three components: thin clients, a server, and maintenance service (see the AND fork in Figure 4 labeled with (1)). To give an example of the dependent paths, consider the value exchanges related to the thin clients (2), which consists of acquisition of thin clients (3) and energy consumption of these thin clients (4). The acquisition of thin clients requires value exchange with the hardware suppliers (5) and the use of these thin clients

³ The MJA is a voluntary agreement between the Dutch government and the largest energy consumers in the Netherlands, these being both large industries (e.g. banks and telecom providers) and higher education institutes (e.g. universities).

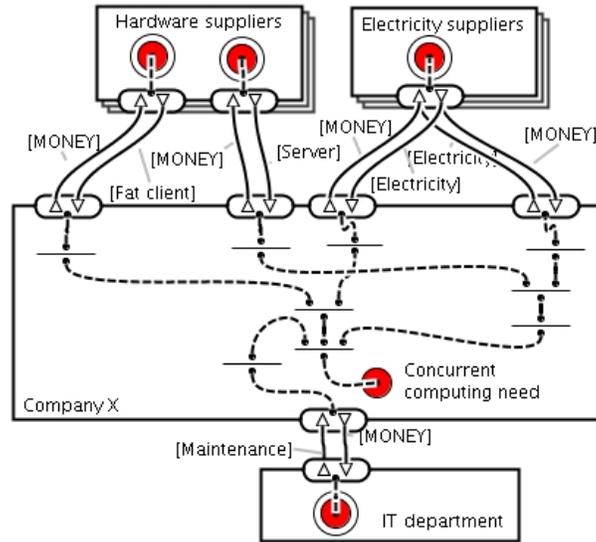


Fig. 3 Usage of fat clients, without virtualization

requires electricity, which requires another value exchange with the electricity suppliers (7). Since the electricity is charged per month whereas the computing need is charged for three years, the fork (6) automatically normalizes costs in 1-month fractions.

After modeling the actors and value exchanges between them, we assigned parameters (with assumptions) to each value exchange in order to estimate the costs. The parameters we assigned for the two situations are listed in Table 1.

Table 1 The parameters assigned to As-Is and To-Be situations

Attribute	As-Is situation	To-Be situation
Number and type of clients	50 fat clients	50 thin clients
Price for each clients	600 euro	400 euro
Number of servers	1	1
Energy consumption of a client per month	$180W * 10h * 22d = 39.6kW$	$20W * 10h * 22d = 4.4 KW$
Energy consumption of a server per month	$250W * 24h * 30d = 180kW$	$400W * 24h * 30d = 288KW$
Price of energy per kWh	0.5 euro	0.5 euro
Maintenance cost per client per year	50 euro	25 euro
Maintenance cost per server per year	400 euro	400 euro
Desktop virtualization software license per n/a year		400 euro

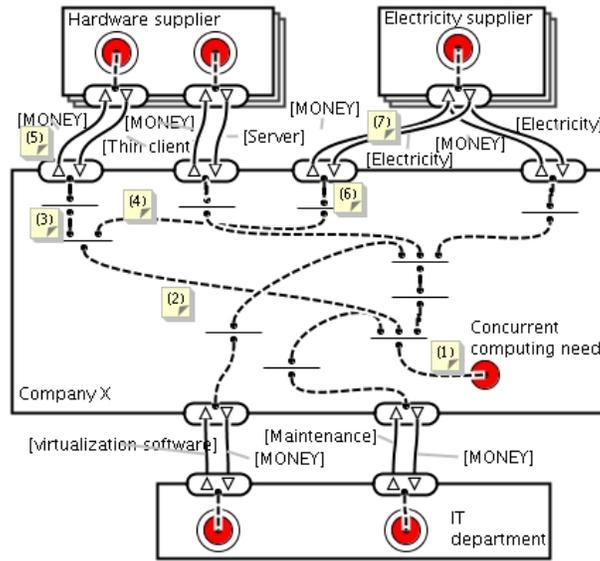


Fig. 4 Usage of thin clients, with virtualization

With the provided parameters, the e^3value modeling tool generated a spreadsheet that calculates the costs spent and revenue gained by each actor after three years. From the report, we could quantify the economic benefits that we should expect by reusing the green ICT practice:

- Energy consumption costs of client workstations is decreased by 88.8%.
- Energy consumption costs of servers is increased by 37.5%.
- Acquisition of thin clients requires an investment of 20,000 euro.
- Desktop virtualization software license requires an investment of 1,200 euro.

In this example estimation results show that the applied practice would lead to an overall 47% reduction of expenses and 20% reduction of electricity consumption. However, when using the e^3value management tool, these measurements and a comparative analysis have to be manually calculated by users what converts this procedure into a tedious task. Therefore there is a need for automatization to help users in this decision making process.

4.1 Findings

In general, we have been able to model all relevant fields in the original MJA document using e^3value according to our model. This gives us confidence on its suitability in modeling green strategies. The next step, however, would be to go back to

the companies, or involve other ones, to check if our way to align economic impact and environmental benefits is effective and sufficient to decide on the best fitting strategy.

For the sake of readability, the green practice in our experiment has been modeled in a simplified yet realistic context.

1. We limited the number of actors, including only the ones that are essential and highly relevant to the green practice. In real life, thin clients and fat clients can be purchased from multiple vendors in multiple times and with potentially different prices. To simplify the models, we assumed that all the equipment is purchased from a set of vendors concurrently with a fixed price.
2. We simplified the calculation of electricity tariff. Electricity prices may vary depending on regions, countries, distribution network of the same country, type of customers, and type of contracts. In this experiment, we assumed that electricity is provided by a set of providers of the same type and with a fixed rate. However, rates are all taken from real providers.
3. We constructed the relation between IT maintenance and the company in a simplified manner. In reality, the way in which IT services are arranged can be quite complex and the cost for IT maintenance can be charged differently. In this experiment, we assumed an average maintenance cost per hardware per year. In addition, often a company already has a number of computers in use; when deciding to apply desktop virtualization, the disposal cost of legacy hardware equipment should also be considered. Customization is needed when modeling the value exchanges and estimating the expected ROIs in real scenarios.

Further, the case study allowed us to collect the following additional observations on the codification as well as a list of issues that should lead to further improvements to our strategy model.

- Advantages of using *e³value* in alignment with our green strategy model:
 - **The understandability of green actions is improved.**
As we mentioned earlier, the green actions provided to us was documented by domain experts who made assumptions that readers having sufficient background knowledge to understand. However, when shared with other data centers or presented to a third party (e.g. our university for research purposes), the documented green actions are often not completely understandable and less usable. By modeling the green actions, they are easier to be shared and communicated since assumptions and domain knowledge embedded in the descriptions become explicit. For instance, in our description of the scenario the consequences of using fat/thin clients with/out virtualization are less clear to the reader before modeling. Only after modeling it is clear that from environmental perspective it would use less energy (lower carbon footprint) and maintenance, and from economic perspective it saves costs for energy consumption and saves costs for maintenance. Knowing these consequences is essential for companies to understand and select the green action.

– **Searching and selecting green actions for specific purposes becomes easier.**

Very often, a company would search for green actions to achieve certain environmental goals, which is also the purpose of sharing green actions among multiple data centers under MJA agreement. When action effects and economical impacts are explicit, they can be used as criteria for companies to search for green actions that fulfill their business requirement. Further, explicit action effects and economical impacts may aid companies to justify and reason about the selection of certain green actions.

– **The completeness of the documentation of green actions is improved.**

The model encourages the author of a green action to document and, most importantly, to think about the environmental effects and economic impact that the green action may bring. In the future, when the green strategy model is commonly used for documenting green actions, the authors are guided with what type of critical information to provided. As a result, the chance that the documentation of green actions is complete is much higher.

– **Dependences between green actions are modeled.**

When modeling the green actions, we observed that some green actions are dependent or related to each other. For example, one green action could be to use adiabatic cooling for the resources of a data center, meaning that “as a complement to the direct free cooling we can evaporate water into the airflow to remove the heat in the air”. Another similar green action is described as “Moistening and drying air are expensive and energy intensive. Use equipment that operates between 20% and 80% of relative humidity.” The former action results in high humidity of the air; and the latter action proposes to use devices that may tolerate wider ranges of humidity so that no extra efforts are needed to moisten or dry air. Obviously, the latter action provides a solution for the problem that the former action introduces. If such relation is explicitly modeled, it is easier to justify the economic impact of both green actions as a whole.

– **Advantages of visualizing value exchanges**

The results show that the models in our experiment well simulate the value exchanges under the simplified context and make the economic value of the green practice explicit. The *e³value* technique provides a graphical overview of a resource exchanging network of a company. The visualization of participants and their relations in terms of value exchanges aids the analysis of the economic viability of the network. Therefore the *e³value* technique helps to consider a green practice in the context of the business model of a company, it encourages the alignment between business strategies and environmental ICT solutions.

Explicitly modeling the resource exchanges related to green practices within the business model of a company also urges ICT technicians to be aware of

economic value of certain ICT solutions. Technicians often consider only quality attributes (e.g. performance, security) when proposing ICT solutions to meet business needs of a company. The short- and long- term economic impact of the ICT solutions, however, often get little attention, as long as the solutions meet the budget planned. Using the e^3value technique, ICT technicians are able to compare alternative ICT solutions, especially from the economic perspective, and decide the one that suits best the company's needs. For instance, desktop virtualization can be implemented in many different ways: by using thin clients and storing the "virtualized desktop images" on a central server (as we modeled in our experiment); or by running multiple virtual machines on local hardware such as laptops without a server. While the former requires a central image management software, the latter requires the realization of desktop virtual machines. These two solutions may require different actors and different value exchanges. With the help of the e^3value technique, technicians are able to compare the economic influence of different solutions and thus make informed decisions.

– **The e^3value technique versus spreadsheet applications**

One could argue that without using the e^3value technique, a spreadsheet application, such as excel sheet, recoding and calculating the cost would also be sufficient. We agree that using excel (or similar software tools) would be computationally equivalent to the e^3value modeling tool in terms of the calculation of costs. In fact, the report generated by the e^3value modeling tool is in the form of excel spreadsheets. However, e^3value models are different from spreadsheet applications, which focus only on numbers and calculations. The e^3value modeling tool, instead, provides a graphical interface both for illustrating the inter-related financial dependencies between actors for filling parameters by end-users. The e^3value model cannot be replaced by any spreadsheet applications specifically because it helps to achieve the following two goals:

1. To support communication of green practices among different types of stakeholders. While technical stakeholders would be comfortable in working directly with formulas and textual calculation (like in Excel), there is the need to communicate about a practice with business people and strategic decision makers.
2. To facilitate reuse of the same green practice in different organizations having different ways of implementing them (e.g. because of different departments involved, or different factors that are variable in one company and constant in another). Whenever a practice should be reused, its contextualization changes. While applying the changes in a visual model is straightforward (assuming one knows the modeling notation), applying the same changes in a textual calculation (like in Excel) is error prone and hinders reuse.

- For demonstration purposes, we show that it is feasible to use the e^3 value technique to estimate the economic impact of green practices. However, there are few issues for further improvement:
 - **Support for differentiation between positive and negative impacts.**

In the case study, we observed that each green action can have multiple economic impacts, which may be positive (i.e. contributing to reduce costs and increase benefits) and/or negative (i.e. require investments to put the actions in place). Currently, both of the two types of economic impacts are codified by one element (i.e. economic impact) without the discrimination of positive and negative effect. To assess the ROI of a strategy and align it to the organization business objectives is of course necessary to gain clear understanding of both positive and negative economic impacts. Therefore, in our opinion the discrimination of positive and negative impacts should be supported by the model.
 - **Include references to the application of green actions.**

We noticed in the MJA document that sometimes reference documentation, a case of study or examples are given to show the application or usage of a green action. In our opinion, the information about the practice of a green action is very relevant to give the reader an instrument to get better understanding on a green action, and therefore, should be supported by the model.
 - **Support for model customization.**

The models can be further customized to a real case scenario with actual actors and pricing, and most importantly, a real life business model. Similarly, the energy consumption of hardware devices should be measured instead of estimated to improve the accuracy of the cost estimation.
 - **Support a comparative analysis of economic implications for short and long-term investments.**

We noticed that short-term investments (e.g. acquisition of hardware devices) and long-term costs (e.g. energy consumption) should be distinguished and analyzed in order to provide a thorough estimation of economic impact of green practices.

5 A Web-Based Calculator for Green ICT Practices

Our findings emphasize the need for a quantitative assessment of the economic benefits of green ICT. For this reason, we developed and released a Green ICT Web Calculator, a Web Application able to estimate the ROI of applying a green ICT

practice. In this section, we explain our approach and the implementation of the calculator.

Our first step was to collect and elicit green ICT metrics from both practice and literature. We performed a systematic literature review [3] that resulted in 66 green metrics, classified in 5 categories: Energy, Performance, Economic, Utilization, Pollution. Examples of relevant metrics identified in this study are: Energy Consumption, Energy Savings, Client/Server Energy Costs.

Another study we performed [10] was more focused on metrics commonly used in industry. This study evaluated practices in four different focus areas: Embedded System Software, Generic Software, Data Centers/High Performance Computing and Hardware. Relevant practices identified in this study were Total Cost of Ownership (TCO), Power Usage Effectiveness (PUE), Energy from Renewable Sources.

Finally, we performed a case study in partnership with a multi-national telecommunication organization, where we designed a framework called “Value of Energy” [9]. In this framework, we defined several metrics for data management in the Cloud, that can be applied to calculate the economic value of data management practices. Some examples of Value of Energy metrics are: Effective Power (power used to store valuable data in the organization), WastedPower (power used to store obsolete data that can be deleted or archived), Future Amount of Data (the expected amount of data in the future, according to data growth statistics). Using this previous work as reference, we carried out additional research to analyze and build a consistent set of metrics for green ICT.

5.1 Formalization of green ICT metrics

As a result of the aforementioned studies, we elicited several metrics to describe the environmental and economic benefits of green ICT practices. Here follows a list of the relevant metrics embedded in the Web Calculator according to the implemented practices. However, as shown above, this list is part of a considerable knowledge base we built, that allows us to easily extend the Web-based Calculator with additional practices.

- Electricity (kWh)
- Carbon emissions (g/kWh)
- Capital Expenditures - CAPEX (€)
 - Hardware
 - Software
 - Service
- Operational Expenditures - OPEX (€)
 - Electricity cost
- Equipment Lifespan (years)

- E-waste (kg)

Carbon emissions is used to estimate savings in CO₂emissions when adopting a green ICT practice. To obtain this value, the Electricity metric is multiplied by a number which represents the CO₂ grams per KWh emitted in the electricity plants of the Netherlands (normalized average), namely 597 grams per KWh. This value has been calculated by means of the measures shown in Table 2.

Type of fuel	Emissions (g/kWh)	Plant Power (MWe ⁴)
Gas	430	5400
Coal	900	3943
Nuclear	6	485
neRenewable	0	37

Table 2 - Emissions and types of power plants in the Netherlands

CAPEX is the amount of money (in Euro) to be invested in capital expenditures before the adoption of a green ICT practice. It can be further divided into Hardware, Software and Service (maintenance, periodic licenses) costs.

OPEX is the amount of money (in Euro) to be spent on operational expenditures during the adoption of a green ICT practice. This includes Electricity cost that is derived from the Electricity metric according to the relative energy tariff.

Equipment lifespan is used to express how long IT devices can be functional, and thus, when they should be replaced. The replacement will involve a periodical payment.

E-waste expresses the quantity of IT material that has to be disposed of. This metric has an inverse relationship with the Equipment Lifespan metric.

5.2 The Application

The *Web Calculator*⁵ is an online web application that helps decision makers calculate the cost benefits of green ICT practices. To ease this achievement, the Web Calculator has been partially integrated with our online library of *Green ICT practices*⁶ thus allowing users to immediately calculate an economic estimation of applying a specific practice in their organizations. Up to now, the Thin Client practice from the green ICT library has been implemented in the Web Calculator. As part of our future work, additional practices will be also modeled and integrated.

⁵ http://greenpractice.few.vu.nl/index.php/calculator/step_1

⁶ <http://greenpractice.few.vu.nl/>

The Web Calculator has been developed as a PHP Web Application. Along with the PHP programming language, CSS stylesheets and JavaScript are used to improve user interface in terms of usability and aesthetics.

The Web Calculator consists of two modules: model management and selection-processing of models. The first module offers features to find, upload and retrieve models. The second module is divided in four sub-steps on which users select previously loaded models, configure them and calculate investments and expenses according to the modeled practice. After the execution, charts of the results are available to users, to provide visualization of the economic benefits.

Figure 5 shows the execution flow of the application. The various phases are described in detail in the remainder of this section.

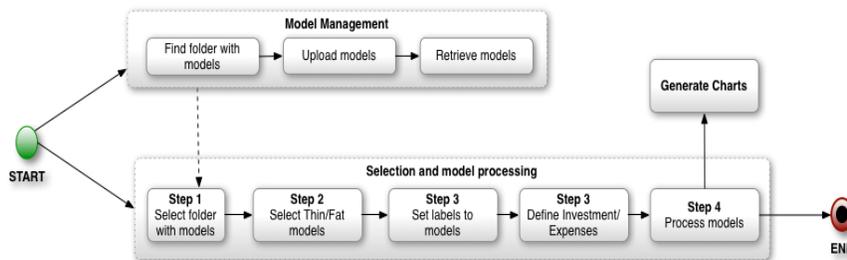


Fig. 5 Usage diagram of the Web Calculator.

5.2.1 Features of the Calculator

Model management

Through the *e³value* modeling tool, it is possible to generate Excel spreadsheets that implement the models for green ICT practices. The file manager of the Web Calculator helps users to organize the different models in a meaningful structure for easier manipulation. In Figure 6 we show a screenshot of the Model Management interface. In the list below you can find all the available file management operations:

- View and sort files/folders
- Upload new files
- Create files/folders
- Search in files/folders

Thanks to this feature, the Web Calculator is easily extensible, allowing users to estimate the economic effects of new green ICT practices. However, the Excel spreadsheets have to be generated from the *e³value* modeling tool, in order to be properly parsed by the Web Calculator.

Files			Sort by name
—	e3value_files	18 files	1
◊	models	2 files	1
—	thin model	2 files	1
		3 folders	0 files

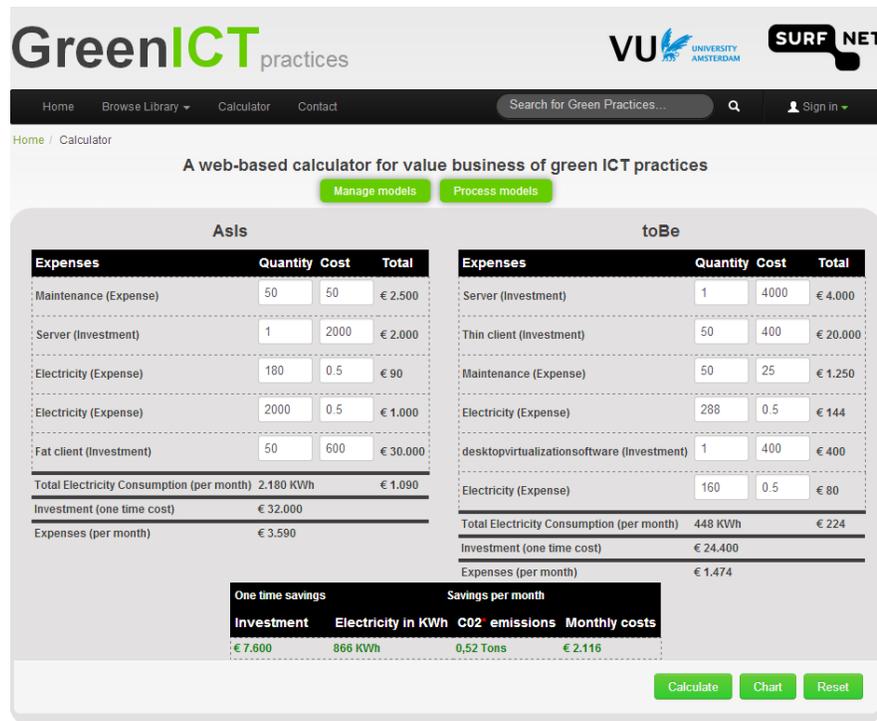
Fig. 6 Model Management interface

Selection and processing of models

Models can be selected and configured from within the Web Calculator interface. Users are able to give each model a meaningful label for comparison and, more importantly, they can customize the *value exchanges*, which represent the actions between the actors of the model. For example, the electricity provider (actor) exchanges electricity for money with the company (actor). These value exchanges can be either an Investment or a monthly Expense depending on whether exchanges occurs once or every month. In the example before, electricity is a monthly expense because companies calculate electricity as a monthly cost. After defining these properties, users can process the models and visualize the results through charts.

The main feature of the Web Calculator is model execution. Before the execution, users can customize the parameters related to the green ICT practice selected. For the Desktop Virtualization practice, such parameters can be the number

of clients/servers, the cost of the equipment, the electricity consumption and the cost of electricity. This allows users to tune the calculation of the economic benefits of the practice according to their specific situation.



*597 grams per KWh. Based on Jean-Pierre BOURDIER analysis and according to the electricity power plants in Netherlands

Fig. 7 Processed models.

The Web Calculator loads the user-defined parameters into the equations of the model and calculates the results. Figure 7 shows a screenshot of the model execution interface. By default, the application shows two types of potential savings: one time savings and monthly savings. One time savings include the investment savings, while monthly savings include electricity consumption (in KWh), CO₂ emissions and monthly costs.

Chart Generation

The Web Calculator also features the possibility to visualize the results of the model processing phase. Figure 8 gives an example of the Chart Generation feature for the Desktop Virtualization practice. Charts display the calculated metrics for a given

period of time which by default is 12 months. The charts show the difference in terms of monthly costs and payback time between the as-is (Fat Clients) and to-be (Thin Clients) situation.

Moreover, two additional visualizations demonstrate the electricity savings in KWh and the CO₂ emissions savings. For example, in Figure 8 it can be observed how applying the Desktop Virtualization practice reduces the costs (comparing the AsIs and ToBe lines in the top left chart) and shortens the payback time (bottom left chart). The right-side charts show the progression of CO₂ and electricity savings: for example, after 5 months of applying the Desktop Virtualization practice, we estimate to reduce CO₂ emissions by more than 2.5 tons. The period of time can be modified by the user and the charts are automatically updated.

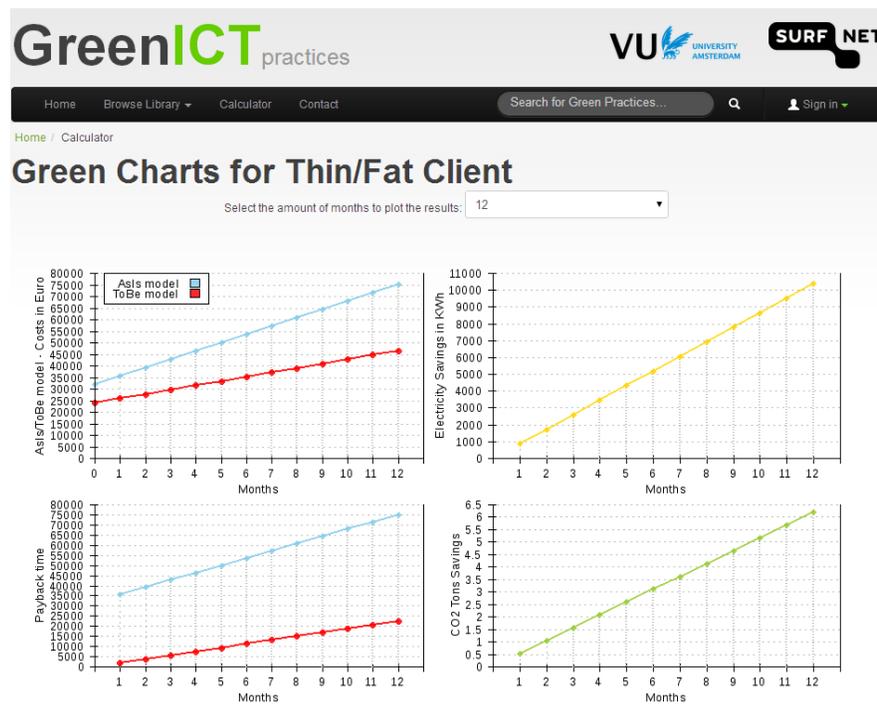


Fig. 8 Visualization of results.

6 Conclusions

To reduce energy costs and contribute to global environmental goals, organizations consider green ICT practices increasingly often. Sometimes they even add them as

part of their organizational strategies. However, experience shows that if green ICT practices are not in line with business and organization strategies they are easily neglected, or withdrawn in times of crisis.

To aid organizations in the selection of green ICT practices and aligning them to their business strategies, we applied the *e³value* technique to estimate the economic benefits of applying green ICT practices. Such economic benefits can be influenced by various aspects including investment cost, size of companies, pricing and duration. The application of *e³value* technique allows to perform trade-off analysis to select among different green ICT practices, particularly from an economic perspective. When costs are quantified and ROI is estimated, informed decisions can be made before actual investments.

Most green ICT practices do not yet particularly address software-specific aspects. Our approach allows to clearly separate the role of software (e.g. virtualization software in the experiment here presented) from the role of other factors, and calculate its direct and indirect economic impact.

Our contribution is two-fold: first of all, we provide a rationale for promoting sustainability in organizations and a stimulus to identify and formalize new green ICT practices for achieving more profitable results. Secondly, we provide an educational tool to explain environmental benefits of re-greening ICT, as well as the relation with economic investments, gains, and ROI.

The Web Calculator represents a first step towards calculating the economic benefits of green ICT: it provides estimations of the economic impact of green ICT practices, allowing organizations to reuse these practices through informed decisions. Our future work will be devoted to empirically validate the estimations of the Web Calculator, through industrial case studies in collaboration with our partners SURF⁷ and Green IT Amsterdam⁸.

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⁷ <http://www.surf.nl/en/about-surf/subsidiaries/surfnet>

⁸ www.greenitamsterdam.nl/

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