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## Green Computing Practices and Sustainable IT Performance: The Mediating Role of Energy Efficiency and the Moderating Role of Environmental Management Capability

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| ARTICLE INFO                                                                                                                                                                                                                                                                                                                                                                                                                                                                | ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
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| <p><b>Received:</b><br/>March 24, 2026</p> <p><b>Revised:</b><br/>April 19, 2026</p> <p><b>Accepted:</b><br/>May 10, 2026</p> <p><b>Available Online:</b><br/>May 27, 2026</p> <p><b>Keywords:</b></p> <p>Green Computing Practices, Energy-Efficiency, Environmental Management Capability, Sustainable IT Performance, PLS-SEM, Mediation, Moderation.</p> <p><b>Corresponding Author:</b><br/><a href="mailto:amiriqbalmahar@gmail.com">amiriqbalmahar@gmail.com</a></p> | <p>The study analyzes the relationship among green computing practices, sustainable IT performance, and knowledge of mediating and moderating roles of the energy efficiency and environmental management capability within the scope of information technology (IT) firms and institutions. For data collection, a cross-sectional organizational survey was used, involving IT professionals and personnel responsible for sustainability. For the measurement, multi-item scales for green computing practices, energy efficiency, environmental management capability, and sustainable IT performance were used. Data was collected using a cross-sectional organizational survey design, with IT professionals and personnel responsible for sustainability used. Multi item scales were used for the measures of green computing practices, energy efficiency, environmental management capability, and sustainable IT performance. After data cleaning, we tested the constructs for data validation by carrying out confirmatory factor analysis (CFA) and discriminant validity was tested by heterotrait monotrait ratio (HTMT). It was decided to use the Partial Least Squares Structural Equation Modeling (PLS-SEM) technique because the proposed sustainability model represents a complex mediation-moderation model and is also predictive in nature. Path analysis with bootstrapped indirect effects and interaction-term analysis/slope significance testing were used to test the mediating role of energy efficiency and the moderating effect of environmental management capability, respectively. Model evaluation were performed using the standardized root mean square residual (SRMR), <math>R^2</math>, <math>Q^2</math>, and the predictive relevance assessment (PLSpredict) of the model. The measurement model showed good reliability, convergent validity and discriminant validity across all constructs and measures did not exceed recommended limit on overall model fit indices. The outcomes of the structural analysis revealed that energy efficiency has a significant positive relationship with green computing practices and sustainable IT performance, the relationship between energy efficiency and sustainable IT performance is significant and positive, and energy efficiency acts as a partial mediator/mediating variable in the relationship between green computing practices and sustainable IT performance. The capability of environmental management was determined as a significant mediator between energy efficiency and sustainable IT performance, being more influential among the firms which had higher environmental management capabilities. PLSpredict analysis indicated good out-of-sample predictive power for the model. The results indicate that investment in green computing can ensure sustainable IT performance significantly from a better energy use perspective, and the role of organizational environmental management capability in this transformation is significant, which provides implications for IT companies on matching the issues of "environmental management capabilities" and "sustainability strategy".</p> |

## Introduction

Data centres, enterprise computing systems, networking infrastructure and energy-all-consuming information technology infrastructure are all taking a significant and growing share of the global electricity grid, resulting in a meaningful and growing contribution of global energy consumption and carbon emissions. (Murugesan, 2008). Green computing is an emerging issue that has received considerable attention in recent times; defined as the 'de-sign, make-use, and dispose of computing resources according to an environmental responsibility perspective', has transitioned from a peripheral corporate social responsibility concern to a critical issue which has the potential to become a strategic operational concern of many IT firms and institutions (Murugesan & Gangadharan, 2012) as the organization is increasingly subjected to regulation, stakeholder pressure and competition to reduce environmental impact. Most of the practices for green computing are organization-oriented initiatives that range across a broad spectrum of attempts to make IT more energy efficient in its hardware consumption, virtualization and server consolidation, optimizing the cooling of data centers, using power management software and strategies for reducing e-waste through a lifecycle approach, which are aimed at minimizing the environmental impact of IT usage, with the goal ideally being to help rather than hinder organizational performance objectives (Uddin & Rahman, 2012). This framing to information systems and IT infrastructure as not only a contributor to but also a potential solution to environmental sustainability problems paves the way for another line of information systems work that examines the role of IT in ecological sustainability (Chen, Boudreau, & Watson, 2008; Watson, Boudreau, & Chen, 2010).

Although firms are investing in green computing programs, how green computing actually contributes to sustainable IT performance – both in terms of environmental outcomes and operational/service outcomes – is not well understood. The benefits of green computing practices on sustainable IT performance do not occur automatically and directly; instead, the quantifiable benefits of these practices—particularly energy efficiency, the immediate consequence that is most directly impacted by practices like load balancing, hardware optimization, and virtualization (Uddin & Rahman, 2012)—must be achieved. Therefore, energy efficiency, which is usually measured as 'useful computing output per unit of energy consumed' constitutes instead a critical intervening mechanism between green computing practices and the wider sustainable IT performance outcomes, and not all green computing practices and outcomes of sustainable IT are necessarily directly and unconditionally also connected (Mingay, 2007). While an organization can have a variety of green computing activities and measures, without having a meaningful improvement in the energy efficiency of IT use in practice— perhaps because these activities are not implemented correctly, the energy use is not properly monitored, or the use of green computing tools is not integrated and included in their core IT operations—in such cases, they may realize limited improvement in energy efficient IT performance.

At the same time, the impact of the wider translation from energy efficiency into sustainable IT performance outcomes will not be the same in all organizations but is a function of the organization's greater environmental management capability, which includes the systems, processes and managerial skills an organization has for setting environmental goals, measuring environmental performance and embedding environmental considerations within the core business processes (Judge & Douglas, 1998). Because of their higher level of environmental management capability (EMC), organizations that can demonstrate it, such as through formal environmental management systems, sustainability staff and environmental performance monitoring processes, may be better able to identify, quantify, and achieve the energy efficiency benefits of green computing efforts, and to realize those benefits in terms of broader sustainable IT performance outcomes than those with lower levels of EMC (Russo & Fouts, 1997). This implies the capability of environmental management can have both direct and indirect impacts on sustainable IT performance while also potentially mixing with the relationship between energy efficiency and sustainable IT performance specifically.

Despite the conceptual plausibility of this mediated, moderated structure, few empirical studies have tested energy efficiency explicitly as a mediator between green computing practices and sustainable IT performance, while at the same time moderated the downstream part of this mediated structure using environmental management capability as a moderator in an integrated structure. The literature available on green IT has largely focused upon the direct relationship between green computing (GC) adoption and organizational (or environmental) performance (Molla & Abareshi, 2012), or has investigated environmental management capability on its own as an independent predictor of environmental performance, but not within the context of the adoption of green computer (Molla & Abareshi, 2012; Russo & Fouts, 1997).

Since this study encompasses the two components of both mediation and moderation and a predictive nature of sustainability models like this, it is important to examine the matter by applying a method that has proven strong in handling such models with relatively few distributional assumptions compared to the covariance-based models, such as Partial Least Squares Structural Equation Modeling (PLS-SEM) (Hair, Risher, Sarstedt, & Ringle, 2019). This integration follows the demonstrated needs in the information systems literature to research how the organisational mechanisms which connect the environmental

efforts enabled by information technology to the dimensions of sustainability are mostly related to one another, and to their direct connectivity rather than an unconditional relationship (Melville, 2010). Using the methodologically solid PLS-SEM framework and fit assessment criteria for SRMR and out-of-sample predictive assessment for  $R^2$ ,  $Q^2$ , and PLSpredict, this project points to a methodologically robust and predictively tested path of change between investments in green computing and better sustainable IT performance, as well as the organizational capability conditions under which it is achieved most effectively.

The aim of this research is four fold, one, to investigate the direct relationship between green computing practices and sustainable IT performance; two, to investigate the relationship between green computing practices and energy efficiency, and the relationship between energy efficiency and sustainable IT performance; three, to test the intervening process between green computing practices and sustainable IT performance; and four, to test the moderating effect of environmental management capability to the direct relationship between energy efficiency and sustainable IT performance. The present study represents a contribution to literature on green IT and sustainability by adding mediation and moderation mechanisms and conducting rigorous measurement and model-fit validation procedures such as CFA, application of HTMT-based discriminant validity and SRMR-based fit measure, as well as PLSpredict-based out-of-sample predictive evaluation, which is a little-known but increasingly recognized validity step in PLS-SEM. In practice, the conclusions provide direction to the IT business and institution regarding green computing sustainable IT performance improvement capability and implementation of investment policies. From an action point of view, the results contribute to guiding IT business and institutions on how the implementation of investment policies has to be structured and combined to achieve the maximum sustainable IT performance outcomes from the green computing.

## **Literature Review**

Green computing or Green IT is the research and application of computers, servers, subsystems and their integration which is designed, manufactured, utilized and discarded in efficient and effective energy utilization with minimum or no environmental impact (Murugesan, 2008). Murugesan (2008) introduced an influential model that includes different aspects of green computing practices that continues to guide empirical studies on green computing, including green use (minimize consumption of energy used in computing services), green disposal (refurbish/recycle outdated computing equipment), green design (design new equipment to consume less energy), and green manufacturing (minimize waste created during the manufacturing process). Murugesan and Gangadharan (2012) even extended this framework to the wider context of green information and communication technology strategy and clearly demonstrated that green computing can now be considered not a technical or operational issue, but a broader organizational-based environmental sustainability issue.

In the IT industry, the concept of energy efficiency is considered a separate dimension from the use of green computing practices, however; in fact, it does not necessarily lead to proportional energy efficiency gains (Mingay, 2007). In a thorough review of energy efficiency opportunities for data centers, Uddin and Rahman (2012) identified significant variability in measured energy efficiency gains depending on the depth or quality of energy efficiency implementation – whether data centers are virtualizing systems, consolidating servers or optimizing cooling systems – instead of doing it in a superficial way designed to boost numbers on a spreadsheet. In the context of this study, such a finding directly leads to the new step of conceptualizing “energy efficiency” as a separate intervening mechanism – not as a “green computing” construct-to-be-reduced-to – as opposed to the latter.

Sustainable IT performance, the dependent construct of this study, is considered by the green IT literature to be a combination and trade-off of both environmental performance dimensions like lower carbon footprint and energy consumption and operational performance dimensions like service delivery maintenance and improvement and cost efficiency, rather than compromising one objective in favor of the IT system's operation and effectiveness (Molla & Abareshi, 2012). In the study conducted by Molla and Abareshi (2012) which surveyed green IT adoption among companies, they found that the extent of green IT implementation in other parts of the company's IT governance programs was also found to significantly affect the impact of green IT on environmental performance, indicating that intervening organisational mechanisms were found to affect the relationship between green IT adoption and sustainable outcomes, with this relationship being considerably stronger depending on the extent of green IT practices integration into other part of the organisation IT governance framework.

Much of the broader corporate environmental strategy literature has focused on the study of environmental management capability, with the view that it is a critical factor in determining the successful enterprise environmental management process of transferring environmental initiatives into measurable environmental and business performance outcomes. The relationship between environmental performance and profitability was shown to be significantly affected by the factors of industry growth and organisational capability in the empirical work done by Russo and Fouts (1997), where the same level of

environmental initiative did not create the same performance benefits for organisations, but rather it was moderated by other factors related to the organisation's capability and characteristics – which is consistent with the natural-resource-based view of the firm, which views environmental capability as a potential source for competitive advantage that is subject to moderation by additional complementary organisational resources (Hart, 1995)). This premise that environmental management capability influences recognized organizational performance benefits from environmental initiatives was also supported by the findings of other research, such as Judge and Douglas (1998), which established that the integration of environmental element into strategic planning processes, a key component of environmental management capability, was highly correlated with both environmental and financial performance.

So far, however, few studies have focused on how environmental management capability affects the link between energy efficiency and sustainable deliveries of IT products and services (in addition to being an independent predictor of sustainable IT performance). This distinction is important, in practice, because when environmental management capability modifies this relationship, the same amount of energy efficiency improvement--such as a percentage decrease in energy use per unit of computing output--will be anticipated to generate meaningful differences in sustainable outcomes for an organization's IT use. Theoretically possible as organisations that are better able to measure, report and strategically leverage the benefits of energy efficiency in terms of realised gains can then leverage other sustainability reporting, stakeholder communication and continuous improvement efforts, to amplify its benefits (Wang, Chen, Benitez-Amado, 2015). In addition, Wang, Chen, and Benitez-Amado (2015) investigated how the moderating role of IT-enabled environmental management capability affects the relationships between environmental management programs and the firm's environmental and competitive performance, and concluded that the relationship between environmental management programs and the firm's environmental performance was far larger when the firm possessed strong IT-enabled environmental management capability than when the firm possessed weak IT-enabled environmental management capability, providing direct support for the moderation hypothesis under investigation in the present study.

From a methodological perspective, the popularity of testing models including mediation and moderation structures in the field of green IT and sustainability has led to the adoption of models with a mediation-moderation approach in this field in recent years. Only the relatively favorable performance of PLS-SEM for relatively small sample size, its prediction-oriented rarity (in contrast to models that focus primarily on covariance), and the ability to accommodate complex models in which various constructs interact with one another, make this method increasingly attractive in green IT and sustainability research (Hair et al., 2019). The present study contributes to the lower level of predictive validity of PLS-SEM constructs compared to TCMS, as Henseler, Ringle and Sarstedt (2015) introduced the heterotrait-monotrait ratio of correlations as a more solid discriminant validity measure for the PLS-SEM framework, and Shmueli et al. (2019) implemented the PLSpredict procedure for formally assessing the out-of-sample predictive power of a PLS-SEM model, which the current study aims to improve, as the evaluation of the PLS-SEM model has previously been overreliant on in-sample fit and explanatory power measures.

Building on this body of theory and evidence, the study advances the following hypotheses. According to the rest of the literature related to green IT and the impacts of green computing to the sustainable performance in general, hypothesis 1 (H1) suggests that there is a significant positive linkage between the green computing and sustainable performance of IT, consistent with the hypothesis proposed by Molla and Abareshi (2012). The positive impacts of green computing practices on energy efficiency is one of the fundamental concepts involved in green computing (Uddin & Rahman, 2012), wherein Hypothesis 2 (H2) proposes that there are significant positive impacts of these practices on energy efficiency. In accordance with energy efficiency being a near-term contributor to environmental and operational performance outcomes (Mingay, 2007) it is hypothesised that energy efficiency has a significant relationship with sustainable IT performance (Hypothesis 3, H3). Constructing H1, H2 and H3 together and based on this, Hypothesis 4 (H4) aims at explaining the mediation of energy efficiency between green computing practices and sustainable IT performance. Lastly, the interaction between energy efficiency and the ability to manage environmental conditions (env mgmt capability) and sustainable IT performance (SITP) is proposed in Hypothesis 5 (H5) that states that the relationship between energy efficiency and sustainable IT performance is stronger in the organizations having a higher level of environmental management capability, which indicates stronger potentiality of leaning greater benefit of sustainable IT from energy efficiency when the organizations have a higher level of environmental management capability (Wang et al., 2015; Russo & Fouts, 1997). All these hypotheses are used as the basis for the subsequent PLS-SEM mediation and moderation analysis sections.

## **Methodology**

### **Research Design**

The study used a cross-sectional organizational survey design to analyze the relationship between green computing practices and sustainable IT performance, to examine the mediating role between energy efficiency and the relationship between

sustainable IT performance and green computing practices and to investigate the moderating role between the energy efficiency and the relationship in this case between sustainable IT performance and practical application of green computing in order to examine the applications of energy efficiency in the green computing practices. The advantages of a cross-sectional design over a longitudinal design are that the study aims to test a hypothesized mediated and moderated model among these constructs, as well as to test them with a sample of IT firms/ institutions, instead of ones that undergo change over time. The unit of analysis was the organization and data was gathered from the informants who had knowledge of sustainability and/or IT practices and outcomes, which were IT and sustainability professionals.

### **Population and Sampling**

The target population included IT firms and institutions which had taken up green computing programmes as a part of their IT operations and sustainability related programmes. Eligible 'respondent organizations' asked to participate were asked to have implemented at least one formal 'green computing' practice for at least 1 year by the time the survey was conducted with a view to identifying potentially meaningful practices (maturity). The survey was focused at each participating organization, at the organization's IT managers, sustainability officers or similar individuals that had first-hand knowledge of the organization's green computing, its energy efficiency results, and its environmental management systems. Data cleaning procedures retrieved and retained a total of 310 valid responses from an organizational level.

### **Measures**

All constructs were employed with multi-item reflective scales borrowed from previous literature on measurement applications for green IT and environmental management. The measurements of green computing practices were ascertained by the items designed according to key green computing dimensions which include energy efficient use of hardware, virtualization and server consolidation, power management practices and e-waste reduction; these were adapted from the different scales of green computing practices already developed (Molla & Abareshi, 2012). The indicator on energy efficiency focused on acquiring apparatus that were estimated to improve the efficiency of energy use in computing, in addition to organizational reporting of relevant energy consumption trends, where available. The assessment of environmental management capability involved items related to the presence and maturity of environmental management systems, the monitoring processes, and incorporation of environmental considerations into IT decision making, which are adapted from existing environmental management capability scales developed by Judge & Douglas (1998). IT dependent construction was measured as sustainable IT performance with items that captured both environmental and operational performance, as adopted in this study to conceptually consider sustainable IT performance in its dual nature of environment and operations (carbon emissions benefit and service delivery benefit). All items that asked respondents a scale from 1 to 5 (strongly disagree to strongly agree).

### **Data Collection and Cleaning Procedure**

The data were gathered from a structured self-administered online questionnaire sent to the released respondent organizations for several weeks. Participants' informed consent was obtained before answering the questions, and they were told that their participation would be anonymous and confidential. After data collection a data cleaning process was applied in the dataset before substantive analysis, including screening for missing data, deletion of data from incomplete responses, identifying and eliminating multivariate outliers by use of the so called Mahalanobis distance and checking for common method bias by the full collinearity variance inflation factor (VIF) approach with all constructs yielding VIF values under the conservative threshold of three and one third proving common method bias to be not at all a problem in this data.

### **Data Analysis Technique**

The data were subsequently cleaned and then subjected to confirmatory factor analysis (CFA) to confirm construct validity by computing the standardized factor loading of each construct, composite reliability and average variance extracted (AVE) for each construct and testing the heterotrait-monotrait ratio of correlations (HTMT) for discriminant validity. Given the specifications of the proposed sustainability model that includes mediation-moderation relationships and has a predictive aim, as established by the literature on the use of PLS-SEM for this type of model (Hair et al., 2019), the structural model was estimated using PLS-SEM in SmartPLS software. This intervening effect of energy efficiency between the use of green computing and the usage of sustainable IT performance was examined by bootstrapped indirect effect analysis, bootstrapping procedure with 5,000 resamples to construct 95% bias-corrected CI. To evaluate the modulating effect of environmental management capability on the relationship between energy efficiency and sustainable IT performance, interaction-term analysis was used, where the product-indicator interaction term was added to the structural model and subsequently the simple slope significance test evaluated to classify the conditional effect of energy efficiency at two different levels of EFMC exceeded, respectively, the standard and exceeds. A mean-centered product-indicator interaction term was proposed in the

structural model, and then simple slope significance testing was performed to character the conditional effect of energy efficiency under different levels of EFMC, mean-centered product-indicator and simple slope significance tests, respectively, were added and performed to examine the moderating effect of environmental management capability on the energy efficiency and sustainable IT performance relationship. In addition to the standardized root mean square residual (SRMR) as an overall measure of model fit,  $R^2$  and  $Q^2$  (based on blindfolding) were used to analyze the model's explanatory and predictive relevance for endogenous constructs, and the PLSpredict procedure was used to formally test the model's predictive ability based on a strict k-fold holdout sample approach as recommended by Shmueli et al. (2019).

## Analysis and Results

### Organizational Profile

The sample consisted of IT companies (58.4%) and institutions (41.6%) including educational and public sector organizations that had significant internal IT activity. The average number of years that each respondent organization had spent implementing a green computing initiative was 4.6 years (SD = 2.8). A summary of the organizational profile of the sample is shown in Table 1 below:

**Table 1. Organizational Profile of Respondents (N = 310)**

| Category                                      | Classification                          | Frequency | Percentage (%) |
|-----------------------------------------------|-----------------------------------------|-----------|----------------|
| Organization Type                             | IT Firm                                 | 181       | 58.4           |
|                                               | Institution (Education / Public Sector) | 129       | 41.6           |
| Organization Size                             | Small (< 100 employees)                 | 84        | 27.1           |
|                                               | Medium (100–999)                        | 142       | 45.8           |
|                                               | Large (1,000+)                          | 84        | 27.1           |
| Green Computing Implementation Tenure         | 1–3 years                               | 118       | 38.1           |
|                                               | 4–6 years                               | 126       | 40.6           |
|                                               | More than 6 years                       | 66        | 21.3           |
| Environmental Management System Certification | Certified (e.g., ISO 14001)             | 142       | 45.8           |
|                                               | Not Certified                           | 168       | 54.2           |

Source: Survey data (2026).

### Data Cleaning and Common Method Bias Assessment

The analytic sample consisted of 310 organizational responses following data cleaning when 24 responses were eliminated due to being incomplete or being outlier responses. No significant common method bias was observed as all variables that formed constructs had VIFs less than the highly conservative 3.3 (Kock, 2015).

### Confirmatory Factor Analysis and Reliability

Before the estimation of the structural model, confirmatory factor analysis was performed to check construct validity. The standardized factor loading for every item was above 0.70, and Cronbach's alpha and composite reliability (CR) values for all constructs were above 0.80, indicating good internal consistency reliability and convergent validity providing strong evidence for reliability assessment of all the constructs and items. (As shown in Table 2).

**Table 2. Confirmatory Factor Analysis: Reliability and Convergent Validity**

| Construct                           | Items | Loading Range | Alpha | CR    | AVE   |
|-------------------------------------|-------|---------------|-------|-------|-------|
| Green Computing Practices           | 7     | 0.726–0.841   | 0.872 | 0.904 | 0.595 |
| Energy Efficiency                   | 5     | 0.748–0.856   | 0.851 | 0.892 | 0.624 |
| Environmental Management Capability | 6     | 0.719–0.832   | 0.861 | 0.897 | 0.609 |
| Sustainable IT Performance          | 6     | 0.734–0.847   | 0.868 | 0.901 | 0.616 |

To evaluate the discriminant validity, the heterotrait-monotrait ratio of correlations (HTMT) was used instead of the traditional method of Fornell-Larcker (1981) that is widely adopted in assessing discriminant validity (Henseler, Ringle, & Sarstedt, 2015). The constructs were empirically distinct from each other with all HTMT values being below the conservative value of 0.85 in accordance with Table 3.

**Table 3. Discriminant Validity (HTMT Ratios)**

| Construct                              | 1     | 2     | 3     | 4 |
|----------------------------------------|-------|-------|-------|---|
| 1. Green Computing Practices           | —     |       |       |   |
| 2. Energy Efficiency                   | 0.647 | —     |       |   |
| 3. Environmental Management Capability | 0.512 | 0.586 | —     |   |
| 4. Sustainable IT Performance          | 0.598 | 0.682 | 0.621 | — |

#### Model Fit Assessment

Overall model fit was evaluated adopting the model fit index that was recommended for model evaluation in PLSSSEM, which is the standardized root mean square residual (SRMR), as an alternative to the usually emphasized in the PLSSSEM fit indices of prediction. The values for the estimated model were very good with the overall model fit good at SRMR equal to 0.058, which is lower than cutoff at SRMR of 0.08 (Henseler et al., 2015).

#### Structural Model Results: Direct and Mediation Effects

The developed structural model was found to be good in explaining the variations in energy efficiency ( $R^2 = 0.336$ ) and sustainable IT performance ( $R^2 = 0.448$ ). The blindfold test resulted in a  $Q^2$  of 0.212 for the energy efficiency and a  $Q^2$  of 0.276 for sustainable IT performance, where both  $Q^2$  values were greater than 0. The values of  $Q^2$  were 0.212 for the energy efficiency and 0.276 for sustainable IT performance, both of which are greater than 0, indicating a degree of predictive relevance under the blindfold test. Table 4 shows the structural path result of the hypotheses for testing H1–H3.

**Table 4. Structural Model Results: Direct Effects**

| Hypothesis | Path                                                   | $\beta$ | t-value | p-value | $f^2$ | Decision  |
|------------|--------------------------------------------------------|---------|---------|---------|-------|-----------|
| H1         | Green Computing Practices → Sustainable IT Performance | 0.284   | 5.046   | 0.000   | 0.106 | Supported |
| H2         | Green Computing Practices → Energy Efficiency          | 0.580   | 11.628  | 0.000   | 0.512 | Supported |
| H3         | Energy Efficiency → Sustainable IT Performance         | 0.396   | 6.918   | 0.000   | 0.198 | Supported |

Note. Bootstrapping based on 5,000 resamples; two-tailed test; significance level  $p < 0.05$ .

For Hypothesis 4 examined the mediation between green computing practices and sustainable IT performance on the mediating role of energy efficiency, bootstrapped indirect effects were used. The indirect effect of green computing practices on sustainable IT performance via energy efficiency was statistically significant ( $\beta = 0.230$ ,  $t = 5.384$ , 95% bias corrected CI = [0.146, 0.316]). The results show that energy efficiency is a partial mediator between green computing practices and sustainable IT performance (H1) with 44.7% variance accounted for (VAF). A summary of the mediation analysis is provided in Tab. 5.

**Table 5. Mediation Analysis Results**

| Relationship                                 | Direct Effect ( $\beta$ ) | Indirect Effect ( $\beta$ ) | t (Indirect) | 95% CI         | VAF (%) | Type              |
|----------------------------------------------|---------------------------|-----------------------------|--------------|----------------|---------|-------------------|
| Green Computing → Sustainable IT Performance | 0.284**                   | 0.230**                     | 5.384        | [0.146, 0.316] | 44.7    | Partial Mediation |

Note. \*\*  $p < 0.001$ .

#### Moderation Analysis: Environmental Management Capability

The moderating effect of environmental management capability on the relationship of energy efficiency and sustainable IT performance was tested using the interaction-term analysis by adding a product-indicator interaction term (Energy Efficiency × Environmental Management Capability) to the structural model in order to test the moderation of the direct relationship between energy efficiency and sustainable IT performance. The results of ANOVA analysis indicated that environmental management capability has a positive and significant effect on the relationship between energy efficiency and sustainable IT performance and thus supported Hypothesis 5 (Table 6) with  $f^2 = 0.039$  and  $\beta = 0.176$  and  $t = 3.084$ ,  $p = 0.002$ .

Unfortunately, this was found to be the case, as evidenced by the results of the slope significance test. The results indicate that the energy efficiency-sustainable IT performance path is significantly stronger for organizations with a high environmental management capability simple slope = 0.512,  $p < 0.001$ , than for organizations with a low environmental management capability simple slope = 0.287,  $p < 0.001$ ).

**Table 6. Moderation Analysis Results (Interaction-Term and Slope Significance Testing)**

| Path / Effect                                                          | $\beta$ | t-value | p-value | $f^2$ | Decision     |
|------------------------------------------------------------------------|---------|---------|---------|-------|--------------|
| Environmental Mgmt. Capability → Sustainable IT Performance (direct)   | 0.158   | 2.764   | 0.006   | 0.034 | Significant  |
| Energy Efficiency × Env. Mgmt. Capability → Sustainable IT Performance | 0.176   | 3.084   | 0.002   | 0.039 | H5 Supported |
| Simple Slope: High Environmental Mgmt. Capability                      | 0.512   | 8.246   | 0.000   | —     | —            |
| Simple Slope: Low Environmental Mgmt. Capability                       | 0.287   | 4.892   | 0.000   | —     | —            |

Note. Interaction term constructed using mean-centered indicators prior to product term formation, consistent with standard PLS-SEM moderation procedures.

#### Predictive Relevance Assessment (PLSpredict)

In order to formally compare the out-of-sample predictive ability of the model with that of the naive linear model (LM) benchmark, the PLSpredict procedure was employed with a 10-fold holdout sample strategy, following the advice of Shmueli et al., (2019); this involved computing predictions for each predictor of each endogenous construct of the model using 10-fold holdout samples. Table 7 shows that the PLS-SEM model showed comparatively lower root mean square error (RMSE) values for both endogenously created constructs than expected from the naive linear model, signifying that the model has better ability to explain the variance beyond the capacity of a linear predictor.

**Table 7. PLSpredict Out-of-Sample Predictive Assessment**

| Construct (Indicator Average) | PLS-SEM RMSE | LM Benchmark RMSE | Difference |
|-------------------------------|--------------|-------------------|------------|
| Energy Efficiency             | 0.612        | 0.658             | -0.046     |
| Sustainable IT Performance    | 0.587        | 0.624             | -0.037     |

Note. Negative difference values indicate that the PLS-SEM model outperforms the naive linear model benchmark, confirming satisfactory out-of-sample predictive relevance.

All five hypotheses are supported by the results cohesive Whole. Additionally, energy efficiency showed a significant positive direct effect on sustainable IT performance (H3) and partially mediated the effect between green computing practices and sustainable IT performance (H4); on the other hand, environmental management capability significantly moderated the effect of energy efficiency and sustainable IT performance (H5) with the former having a stronger and significant effect when environmental management capability increased. Overall, the satisfactory SRMR, effect sizes and PLSpredict results, combined with the overall good level of fit, provide support for the strength and predictive validity of the estimated model.

#### Discussion

The results of this research strongly support a mediated and moderated research model by which the practices of green computing relate to the IT sustainable performance of IT firms and institutions. A robustly validated PLS-SEM multi-item measurement approach with SRMR-based measure of fit confirms and extends the findings of the central role of green computing initiatives in driving sustainable outcomes (Murugesan, 2008; Molla & Abareshi, 2012) in the face of a significant direct effect on sustainable IT performance (H1), and strong effect on energy efficiency (H2). Overall the variance accounted for for the influence of energy efficiency on sustainable performance of the IT system is close to 45% with confirmed partial mediation (H4), indicating that a large part of the influence of green computing on sustainable IT performance goes mediated by energy efficiency, but that a substantial part of the influence goes direct to the sustainable performance of the IT system outside the mediation of improving energy efficiency alone, and that means beyond e-waste reduction, and an encompassing view on the system impacting on the environment, which signals to stakeholders the value of this computed energy efficiency.

From this mediated model, environmental management capability (H5) plays an important role as a moderator that refined it. Because there is substantial strength in the simple slope from high environmental management capability to high energy efficiency (0.512), as compared to the low capability (0.287), the same energy efficiency improvement will result in a more

significant sustainable IT performance benefit for the organizations with stronger environmental management systems/monitoring processes and with an enhanced embeddedness of environmental concerns in IT decision-making. This finding expands upon, and takes a step beyond, previous studies regarding how environmental management capability influences the realised benefits of energy-related environmental initiatives more generally (Russo & Fouts, 1997; Judge & Douglas, 1998; Wang, Chen, & Benitez-Amado, 2015) and revealed specifically how environmental management capability enhances the downstream process of translating energy-saving benefits into sustainable IT realised performance, assuming it did not affect it alone, as previous studies suggested.

Regarding the practical--predictive value of the estimated model, the results of the PLSpredict assess that the model is superior when compared with the out-of-sample predictive performance of a naive linear model, which is common in previous green IT studies based on PLS-SEM and has limited in-sample-explaining predictive performance measures (Shmueli et al., 2019). This is in line with the positive correlation between trust and inter-organization learning of knowledge found in similar fields, such as the green supply chain–environmental and other aspects of supply chain practices have been shown to increase the achieved performance effect of environmental practices (Cheng, Yeh, & Tu 2008). The findings have important implications for those within the IT industry and institutions. These results indicate that sustainable IT performance is linked with energy efficiency with direct effect, whose function is not full, and therefore even if there is an effort in improving IT energy efficiency, organizations cannot rely solely on it to achieve sustainable IT performance, but instead need to focus on the other direct environmental and operational practices identified by this study, which explain the substantial direct effect between sustainable IT performance and energy efficiency, which is supported only partially by IT energy efficiency improvement. In addition, the moderation results indicate that organizations that want to optimize sustainable performance impacts of their green computing investments should invest in simultaneously developing environmental management skills, such as having formal environmental management systems, environmental management staff, and robust environmental performance monitoring systems, because they can significantly amplify the benefits of investments in energy efficiency.

## **Conclusion**

This study analyzed the connection between energy efficiency and sustainable IT performance and the connection between environmental management capability and sustainable IT performance in 310 IT firms and institutions, as a mediator and a moderator, respectively. The results revealed that green computing practices significantly and positively predict both energy efficiency and sustainable IT performance; the relationship between energy efficiency and sustainable IT performance is significantly positive and mediation testing using the bootstrapping method supported by a CFA-based approach to measurement validation confirmed that the relationship between energy efficiency and sustainable IT performance is mediated by green computing practices; the relationship between energy efficiency and sustainable IT performance is in fact partially mediated by green computing practices; the relationship between energy efficiency and sustainable IT performance is in fact moderated by environmental management capability, and the relationship is notably stronger among organizations with higher environmental management capability. These results validate the usefulness of modeling the impact of green computing on sustainable IT performance as mediated and moderated path instead of as a direct path and provide methodologically rigorous and predictively validated evidence to a green IT literature which examined different constructs frequently in isolation and lacking in in-sample model validation.

## **Recommendations**

Investing in holistic energy-related measures such as energy-efficient equipment, virtualization, and power utilization should be worthwhile for IT companies and institutions, as the positive impact of IT green practices has proven to be apparent not only in energy use, but also in the performance of IT.

At the same time, organizational leadership is urged to invest in improving the organization's environmental management capacity – boasting formal environmental management systems and a defined sustainability monitoring process – as the benefits on sustainability performance of a given energy efficiency are significantly boosted by such capacity.

Although energy efficiency was not the only mechanism found to bring green computing practices into sustainable performance of IT, it was found to be, clearly, the primary one. Hence, energy efficiency should be set as an important but intermediate performance indicator of organisations' green computing efforts.

However, in addition and beyond just energy efficiency, organisations should consider and invest in other aspects of green computing for e.g. e-waste reduction and sustainable procurement and the direct impact of initiatives and practices to become more 'green' has a significant impact on sustainable IT performance which is not directly related to energy efficiency which also aligns with the principles of the circular economy that are beginning to be applied to electronic equipment lifecycle management (Geng & Doberstein, 2008).

Organizations pursuing environmental management system certification, such as ISO 14001, should view this investment as complementary to, rather than separate from, their green computing strategy, given the demonstrated role of environmental management capability in amplifying the returns on green computing investment.

Future research should employ longitudinal designs to clarify the temporal dynamics of the relationships identified in this study, examine additional moderators such as organizational size or industry sector, and extend the model using objectively measured energy consumption data to complement the perceptual measures employed in this study.

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