Greenization of Computing through Information Systems for Sustainable Development: A Top-Bottom Approach

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Abstract
This paper explores greenization of computing for sustainable development. It attempts to look at the concept of greening computing from top-bottom approach as economic and socio-technological advancements persist, so do problems and contradictions become increasingly conspicuous. Generation of energy and its dissipation to environment has always been the key determiner in shaping human history in the past, present, and future, driver of wars, fears, and peace with polarized technical and political dimensions requiring nonlinear approaches for its solution. With current trends involving computing devices performing almost all human activities in an ever-evolving manner, the energy generated is increasingly becoming hazardous and a threat to sustainability but a source for green growth, wealth, and welfare. This suggests looking at the problem of greenization from triple helix perspective where authorities of the university, manufacturing industries, and government parastatals have to deal with the issue of greening through green human resources management to aid in institutionalizing eco-friendliness in theory and practice, action and product manufacturing. The paper raised many issues and discussed them for developing a reliable model that could solve this challenge.

***Keywords**: Greenization, Computing, Sustainable Development, Triple Helix, Green Human Resources Management*

Introduction

The intricate relationship between humans and computing devices has gone far and indispensable that despite resultant consequences of using such technologies, humans cannot anticipate to go back to ancient life to revert the extent of technological degradation (Ahmad & Khan, 2010). Tying sustainability with the world of bits and bytes, machines and programs, developers, and users implies reducing any initiatives or movements to a single enthusiastic base of normative idea: maximizing economic profits but not at the expense of environment, society or future generations (Mocigemba, 2006). That is, sustainable computing concept deals with "reducing complexity and connecting previously unconnected issues" at three levels: product, production, and consumption process (Mocigemba, 2006, p. 166). This makes energy generation and greening organizational procedures and operations to be the two phenomenally important concepts that continually draw the attention of stakeholders in varying perspectives. This is true, as the technology has advanced in such a way it penetrated all human endeavors thereby becoming a necessity for development and survival. That is, computing has advanced greatly and applied in various fields relying heavily on a mixture of people, networks, and hardware, which requires systemic approaches to address seemingly complex problems (Ray, 2012). For instance, in medicine where cutting-edge technologies specifically AI are revolutionizing traditional patient care or hospital facilities, streamline processes, and optimize resource utilization, the entire procedure is transforming into a smart hospital (Božić, 2023). In this sense, AI is applied in many processes such as medical imaging and diagnostics, predictive analytics, NLP, remote patient monitoring, drug discovery, personalized treatment plans, resource management, robotic assistance, healthcare data security, patient engagement and education, (Božić, 2023) to mention but a few.

In addition, in agriculture, AI and other computing operations are used in detecting malformed, decreased yield or diseases such as wilt of plants through unmanned aerial vehicles (UAV) and internet of things (IoT) (Dang et al., 2020). This involves using highly efficient automated plant disease detection system that can monitor plants for increased productivity (Kumar & Sharma, 2018). It goes deeper to the extent of detecting what affects the yields of agricultural produce such as soil moisture (Chatterjeea et al., 2018). This implies that, technology has gone to the level that social security can be strengthened through employing technological machineries to harness agricultural production, which is a step to silence or alleviate poverty globally (Kumar & Sharma, 2018). This is true, as many researchers have pointed out the problems encountered in agricultural production supply chain such as multi-stage, low efficiency, and wastes, etc., one of the best ways to reduce such problems is linking farms with supermarkets through agricultural supermarket docking using big data technology (Dai & Liu, 2020), which forms one of the most complicated computing technologies nowadays.

From another viewpoint, as it is a known fact that, smart city comprises seeming disjointed aggregates (i.e. energy, clean water, fast communication, etc.) geared to work together for a smooth operation of critical infrastructure thereby providing quality environment. This means that, to maintain the efficacy of smart cities, energy management depends solely on data-driven computing such as Smart Meters (SMs) that generate big data, which require smart grid (SG) (Kumari & Tanwar, 2020) and estimated that, the global market of big data will increase by $103 billion in 2027 (Statista cited by Kumari & Tanwar, 2020). To agree with this submission, Wei and Liu, (2020) investigated the regulation-compliant in terms of road freight transportation by companies, drivers, etc. Their study followed a sequence of UN's intervention where it categorized China as one of the 40 countries in 18 years. China alone contributed more than 39 billion tons of total freight transportation in 2018 with high carbon emission thereby disturbing the environment, and this made China to declare in 2009 its readiness to reduce carbon emission by 40-50% in 2020 (Wei & Liu, 2020). The authors cited many researchers who have noted the ways to reduce carbon emission, which include but not limited to effective environmental policies, technology improvement, operational pattern, improvement in the transportation process, reduction in diesel consumption via replacing aged trucks with newer Euro standard trucks with potential of reducing carbon emission to 11.2%, and reassessing delivery routine (Wei & Liu, 2020). To follow this sequence, Azimi et al., (2020) observed that, a single server, depending on its configuration, consumes about 500-1000W, which challenges high cloud computing performance that use multiple CPU sockets and GPUs. Despite this challenge of power consumption, supercomputers and providers use power-capping mechanism to meet electrical specifications and cooling effects of the infrastructure. There are many consequences that follow, which include coordination of CPU sockets and GPUs, swapping of workload between CPUs and GPUs, among others (Azimi et al., 2020). From economic viewpoint, companies' computing power consumption increases steadily at alarming rate thereby reaching a critical point. To indicate this complexity, an e-commerce with 100,000 servers can spend up to $20 million a year. In addition, for AC cooling, it can account for about $10 million annually, which implies that, on a power consumption, a company can spend up to $30 million in a year (Ray, 2012).

On the other hand, for survival and competition to thrive, increased organizational performance and operational excellence to outshine in business environment in an eco-friendly manner, investing in information technology is necessary especially using internet to run sustainable software (Sokiyna & Aqel, 2020). Furthermore, sustainable software, which is a form of software as a service (SaaS), is growing at alarming rate at 7% in 2023. It runs smooth and proficient activities such as return on investment (ROI) by cutting operational expenses at sustainable rate and arrives at a data-driven decision (Sokiyna & Aqel, 2020). The recognition that, sustainable computing comes into play whenever an organization recognizes the importance of consuming and using lightweight energy saved hardware and software applications mostly via cloud computing (Zheng et al., 2018), attracts the attention of stakeholders in this decade. As captured by Rawat et al., (2020) that, there is already a paradigm shift in high-performance computing whereby using Artificial Neural Network, there is maximum improvement in waiting time, execution time, and power consumption in cloud computing. Many programs and interventions have been put in place to reduce power consumption and maximize performance. Examples of such programs include 80 Plus (Mohapatra et al., 2019), training, carbon off-set program (Paul et al., 2023), among others. However, in spite of these programs and interventions to green computing procedures, the problems of environmental degradation continues. The consequences of not addressing these problems result in different environmental catastrophes such as global warming, losing biodiversity, increased depletion of food products, etc. This calls for other researches to be conducted to reduce these effects to the barest minimum. Unless the problem of computing is looked at from the talent management in technology transfer, the problem of sustainable development will continue to affect the planet earth and may hinder successful handing over of the intact world to the next generations. Fundamentally, sustainable environment practices in organizations require "*attraction and selection of employees motivated by environmental concerns*" and exercising good judgement by HRM in recruiting, hiring, training, compensating, developing, and advancing organization's human capital. In addition, proactive environmental strategies are HRM-based (Labella-Fernández & Martínez-del-Río, 2020, p. 1-2). Fortunately, many theories are available that have described knowledge and innovation in relation to environment. One of the key theorists that described the importance of talent management in technology transfer been Ranga and Etzkowitz, (2013). According to them, technology transfer has to involve universities in order to increase graduate capacity with entrepreneurial education and talent to contribute to economic growth via firm formation and job creation (Ranga & Etzkowitz, 2013).

Statement of the Problem

Talent remains one of the excellent qualities of all humans that is badly needed but sadly lacking that makes organizations to search for it in a helter-skelter manner. It presents itself in many different forms, which encompass but not limited to technology, innovation, entrepreneurship, etc. (Ansar & Baloch, 2018). Even though mere presence of talent does not guarantee success in business, talented people are scarce, which makes business enterprises in constant search for the right ones and necessity for managing them. To indicate the importance of talent in an organization, there is a linear increase in research dedicated to it from 2,700,000 in 2004, 5,750,000 in 207, and 24.7 million in 2017 (Ansar & Baloch, 2018).

This implies that, talent is a competency-based human resource management and management practices that deals with developing, retaining, and attracting competent workforce in an organization (Thapliyal, 2019). It is a known fact that, there is a dramatic change in competitive environment from 1980s that brought about opening of a closed employment system of traditional internal labor markets, which resulted in uncertainty in demand and supply of talent (Cappelli & Keller, 2014). This shift presents difficulties and sometime impossibilities in predicting talent pool and because of the speed with technological innovations change, soft skills and sustainability capacities are continually becoming malleable, which challenge institutions specifically human resources managers to think out of the box.

Computing has diversified and penetrated all human endeavors thereby increasing performance of industries at the expense of environmental degradation. This perhaps has relations with the GDP theory development model, which is opposite to green development but promotes resource and environmental loss. This necessitates bringing resource and environmental factors back to the current national economic accounting equation, which gives rise to green GDP accounting system (Wang et al., 2020). It is worthy to note that, sustainability is a negotiation process initiated by social actors experiencing conflicts of long or new traditions capable of moving the hearts of all or a few skewed individuals with global, national or regional significance to balance social, economic, and ecological interests (Mocigemba, 2006). To add to the dilemma, research has shown that, most of the companies are unaware about the green computing especially with regard to energy consumption and dissipation to environment (Uchechukwu et al., 2014). To match the sustainability challenges with computing and talent, a triple helix theory is necessary. This is because, the seeming human abilities that can fix these problems dwell within the talent pool and that, talent has to be nurtured or activated at universities, transferred to firms, and functioned in governments especially in decision-making processes; this is where the relevance of human resources managers comes as they are uniformly distributed in every organization. They can function in recruiting capable hands in academia to impart green computing onto students, recruit workers in organizations to perform activities according to the greening policies, to mention but a few. Unfortunately, linking these issues with HRM is very little or lacking in the literature. This study is an attempt to raise awareness and direct research towards greening computing for a sustainable future.

In order to achieve the objectives of this study, the paper reports according to the following subheadings

Understanding Greenization, Green Computing, and Sustainable Computing

Energy Consumed and Dissipated to the Environment through Computing: Necessity for Sustainable Software?

Triple Helix and Green Human Resources Management: Where They Can Reconcile

Conclusion

Understanding Greenization, Green Computing, and Sustainable Computing

There is an increased recognition from the international community for pursuing green development globally. To begin with, China replaced Japan to become the world's second largest economy in 2010 with GDP of $5878.6 billion but followed with many severely environmental consequences (Wang et al., 2020*). This is true, as the country adopted extensive developments that implied high input, high-energy consumption, and high pollution leading to severe environmental catastrophes. This occurred due to the open policy, which make China to shift from a purely agricultural economy to industrialized economy thereby situated as the second largest economy globally (Fu et al., 2018). For instance, to indicate the high pollution in China, in 2017 alone, China accounted for 27% of the global carbon emission (Wang et al., 2020). As China is one of the largest leading developing countries, based on the extensive development

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model it has had used for quite long realized that, many environmental problems resulted owing to excessive consumption of resources and energy leading to accumulation of pollutants and wastes (Liu et al., 2021). Since 2015, China has proposed a working plan to convert to green development that is equal to the national conditions and in such a way to combat climate change thereby improving the living conditions of its populace (Liu et al., 2021). To be precise, countries around the globe are beginning to understand that, in the pursuit of economic growth, emphasis should be given to improving quality growth not only quantity growth and greening practice has started since 1980s (Wang et al., 2020). That is why many scholars understand that, "*greenization is the process of coordinated development and growth of the systems of the economy, society, and resources and the environment".* The system works in a reversible direction and "*the goals of these systems are green growth, green welfare, and green wealth, respectively*" (Liu et al., 2021, p. 364). The centrality of greenization lies in the low-carbon emission where for more than 100 years earth has been experiencing a warming in its climate, which signalled countries and regions to look inwardly to tackle this menace. This brought about Kyoto Protocol, Bali Roadmap, Copenhagen Accord, and the Paris Agreement (Liu et al., 2021) in order to develop a system that is greener in nature and can affect the sustainability efforts positively.

Fundamentally, there is a proportionate relationship between industrial development and economic development. Industry is at the juxtaposition for ensuring economic, social, resource, and ecological development, which implies the necessity to steer it to a green path that paves the way for the green economy. The ecological resource has a direct link with industrial development, which conversely affects green development and ecological balance (Wang et al., 2020*). For industry to move in a positive direction, green computing is a necessity. Perhaps the epiphany that, extensive use of computing in industrial applications has been increasing sporadically for quite long, green ICT or green computing has attracted the attention of many stakeholders to the extent companies are trying to out-green one another competitively. This arose because energy consumption is growing at the overwhelming rate beyond expectation. That is, there is growing conception of energy used in different situations for different purposes for manufacturing, storing, operating, and cooling computing systems due to the over-reliance of companies on it with severe effects on environment (Ray, 2012). Green computing deals with study and practice of using computing resources efficiently for triple bottom line (people, planet, profit) whose goals are similar to that of chemistry reduce using hazardous substances (such as cadmium, lead, mercury in Apple products (Mocigemba, 2006), maximize energy efficiency, and promote recyclability or biodegradability of products and factory wastes (Ray, 2012). In this sense, it can be argued that, green ICT taxonomy should consist of data centre-related sustainability (i.e. clean energy to power data centres, IT energy measurement, server virtualization, etc.), distributed ICT-related sustainability (i.e. client virtualization, thin client, network efficiency, etc.), and other ICT direct sustainability (i.e. cloud computing services, green procurement policies, to mention but a few) (Paul et al., 2023).

From the growth curve of PC, it is evident that, the increase in the sales of computers is directly proportional to the energy consumption, which necessitates an increased in the demand for power production in developing countries. In other words, there rate at which sales of computer skyrocketed has baffled academia and stakeholders thus drew their attention to conduct many researches in that regard. This continues to pose serious problems to the environment making sustainability proliferating and sustainability in computing to gain prominence (Gupta & Singh, 2016). Sustainability deals with "*a process of negotiation to balance economic, social and ecological interests of different social groups and actors*" (WCED 1987, p. 24 cited in Mocigemba, 2006, p. 164). That is, sustainability is a term used to transfer the political concept popularized in forestry into computer systems that have to do with material components (hardware), informational parts (software), development, and consumption (Mocigemba, 2006). Thus, sustainable computing is an environmentally friendly use of reducing energy requirements for running any computing infrastructure, energy longevity of computing equipment, and ensuring energy consumption from renewable energy sources (Gupta & Singh, 2016). In Germany, as early as 2003 and enforced on 24 March 2006, there was a law directing consumers to hand over the wastes of their handheld devices to collecting points, which would be recycled by producers (Mocigemba, 2006). The debates concerning accepting technology is a continuous endeavor where Hilty et al., (2005, p. 3) cited in Mocigemba, (2005) who note that, "*in what world do we want to live with what kind of technology?*". To add to this dilemma, sustainability is attainable depends largely on transition to a worldwide information and knowledge society (ISF, 1998, p. 12 cited in Mocigemba, 2006, p. 182).

Energy Consumed and Dissipated to the Environment through Computing: Necessity for Sustainable Software?

Energy consumption in computing still receives prominence in the contemporary society where high performance computing environments consume large amount of energy and its cost is skyrocketing at exuberant rate (Lynar et al., 2013). To begin with, cloud computing (CC) is one of the computer operations that consume high energy. CC provides infrastructure, platforms, and software as a service where many users can request for service at the same time. This implies that, resource allocation is an important problem prevalent in CC due to the different users requesting different services, which require different mechanisms for coordinating, managing resources, and responding to users' queries (Fard et al., 2020). Implementing CC has opened many ways through which penetrative applications from scientific, consumer, and business domains flow rapidly, which resulted in high-energy consumption for the operation and maintenance of cloud data centres leading to green cloud environment (Uchechukwu et al., 2014). That is why energy has a primary concern in operating environment, which raises awareness to save it. High-performance computing (HPC) requires high energy. For instance, in 2006, in US alone, the electricity used for data centers accounted for 1.5% total US electricity consumption, which means heat production as a consequence (Lynar et al., 2013).

This is to the extent that, in a grid system, "*when cluster nodes consume and dissipate power, they must be spaced out and aggressively cooled, otherwise, undissipated power causes the temperature to increase rapidly*" (Hsu & Feng, 2005, p. 1 cited in Lynar et al., 2013, p. 2). This implies that, there will be a corresponding increase in the cost of cooling. This is the case as in some server rooms in some research institutes, the cost of cooling raises up to "*70% of the energy used to power the equipment that is being cooled*" (Lynar et al., 2013, p. 2). That is why green computing evolves where its main tenant is to protect environment, optimize energy consumption thereby keeping green environment intact. In other words, it deals with reducing harmful materials. Green computing came into play due to recognition that, major consumers of computers are processors and memory in the servers (Bobby, 2015).

To add to this fact, Uchechukwu et al., (2014, p. 32) noted that, CC has many components, which encompass "information technology (IT) infrastructure including servers, electrical grids, physical infrastructure, storage, network bandwidth, personnel and huge capital expenditure and operational cost". Among all these parts, cloud data centres are the strengths of contemporary IT infrastructure, which implies the need to enhance its efficiency. Many multitier hierarchies of aggregators, routers, and switches connect the cyber-physical system. Energy consumption is paramount in distribution contents in the system requiring networked computing resources from many providers on datacentres throughout the world. As at 2014, the global energy consumption was at 26GW with the growth rate of 12% per annum. For the expenses, in US, datacentres consume about 61 billion KW hours of power in 2006 accounting for the expense of $4.5 billion. There was an increase of energy consumption from 0.8% in 2000 and 1.5% in 2005 with the corresponding CO_2 emission of 1.46 million metric tons, which international organizations call for reduction to 60-80% by 2050. Similarly, in Barcelona medium-sized

Supercomputing Centre, it pays a bill of about £1 million for its energy consumption of 1.2MV, which equals to the power consumption of 1200 houses (Uchechukwu et al., 2014). For energy efficiency computing, "energy-proportional operation can be attained for lightly utilized servers with full-system coordinated idle low-power modes" with reduction of 50% energy consumption (Uchechukwu et al., 2014, p. 34). This raises the necessity for sustainable software and other computing peripherals.

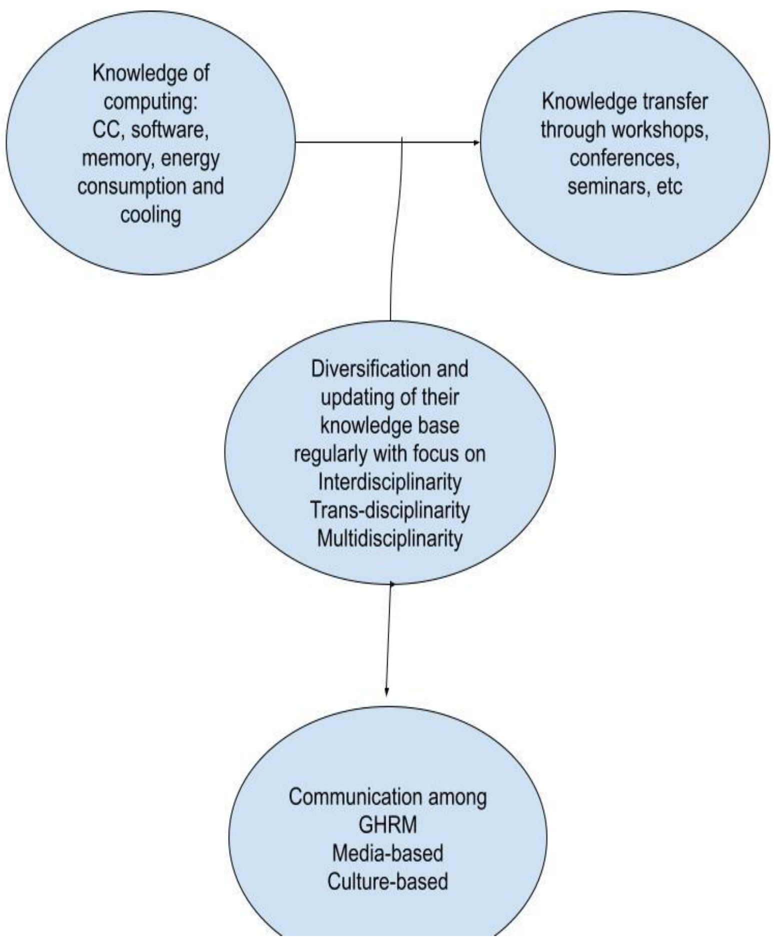
Triple Helix and Green Human Resources Management: Where They Can Reconcile

It follows from the above paragraphs that, knowledge and innovations are a pair that ensures the progress of any society. In view of this, many scholars have tried and are still trying to come up with new discoveries that can inform theory and practice to achieve a sustained environment. To begin with, for long, many researchers have become keenly interested in understanding the relationships between knowledge, innovation, and environment. For knowledge and innovation systems to advance across all level of national development there is a need for a pluralism of knowledge and innovation modes, which needs to encompass structural elements of democracy such as pluralism and diversity (Carayannis & Campbell, 2010). This led Carayannis and Campbell, (2010) to extend the Triple Helix beyond Quadruple Helix to Quintuple Helix where the first indicated knowledge production and use in university-industry-government trios, the second shows the culture-based and media-based component of public, and the third dwelled more on the relationships of knowledge and innovation with respect to the environment. In this sense, circular economy, rooted in resource minimization and cleaner production, is gaining prominence as a way of placing growth on a right pathway for the environment, economy, and society via adopting "*closing-the-loop production patterns*". This requires industrial cooperation with research collaboration and a flow of new knowledge and innovations. Interestingly, this inevitable cooperation can be fulfilled by the interaction of university, industry, and government (Ninikas & Hytiris, 2017). It can be argued that, circular economy is an attempt to integrate "*economic activity and environmental wellbeing in a sustainable way*" (Murray et al., 2017 cited in Ninikas & Hytiris, 2017, p. 2).

Fortunately, for the last two decades, green human resources management (GHRM) became a viable topic at the intersection of corporate environmental sustainability and human resource management (Labella-Fernández & Martínez-del-Río, 2020). That is, it deals with "*people-cantered practices oriented toward developing and maintaining the workforce's abilities, motivation, and opportunities to contribute to an organization's economic and environmental sustainability*" (Labella-Fernández & Martínez-del-Río, 2020, p. 1). Its scope is therefore very wide, as it has to do with the overall environmental sustainability orientation of functions and dimensions of an information system. The best practices inherent in GHRM are "*green recruitment and selection, green education and training, rewards systems, appraisal and performance management, involvement, employee empowerment in environmental issues, green communication, and green teamwork*" (Renwick et al. 2013; Jabbour et al. 2010 cited in Labella-Fernández & Martínez-del-Río, 2020, p. 1). The number of studies amassed to investigate employees contributing to the achievement of sustainability in an organization is enormous and cannot be reported in a single study like the current one. That is, corporate environment issues are diverse, malleable, evolving, and complex that require adaption of companies and employees to address. The complexity of such routine environment procedures need complex knowledge related to product redesign and biodegradable new materials to tally with company's processes leading to little or no polluting products. To approach organizational issues squarely, many things may arise that have to do with ongoing training, motivation, and retention of talented workforce who demonstrates, appreciates, understands, and practices green initiatives (Labella-Fernández & Martínez-del-Río, 2020). Mission statements of many organizations are expressly filled up with sustainability agenda from the stakeholders and regulatory bodies where such provisions are introduced to the lower levels. That is, the direction of the statements flows from top management to middle managers, and later down to employees. Conversely, bottom-up comes up when eco-friendly initiatives emerge from creative ideas of bottom-line employees whose strategies rely on employees' behavior, commitment, involvement, and dedication (Labella-Fernández & Martínez-del-Río, 2020).

Strategizing Greenization in Computing

The roles of GHRM in talent management through information system is wide owing to the fact that, for attracting and retaining talent pool lies within the top and middle management. To begin with, because computing processes involve complex infrastructure, knowledge and mastery of most operations and functions taking place at many levels of CPU, GPU, software, hardware, memory, etc., if GHRM possesses such skills or has qualifications in such fields, it will be of enormous importance towards achieving environmental sustainability. In this sense, subject-specific GHRM is crucial followed by in-depth understanding of computing and its peripherals, and should be part of the decision-making or policy formulation processes and their implementation. At the university level, GHRM should be among the academic team for designing curriculum/syllabus that takes into account green computing initiatives and their full implementation. Secondly, GHRM should have a seat in the faculty or college committees and propose agendas on how to greenize an environment. Thirdly, there should be rewarding of best performing students and develop an idea of developing projects of engaging and encouraging others and incoming students. Fourthly, GHRM should be a member of committee responsible for setting entrance and semester exams for students.



Conclusion

The idea that, organization is just a relative term where people are the real agents spread across different organizations implies that, stemming environmental sustainability and innovation within the framework of university-industry-government is paramount. That is, when people are at the university, they are called students, if they change to industry, they are workers, and if they switch to government, they are authorities. The focus is mainly on people to green computing not organizations. The best mechanism to employ is green human resources management who are the recruiters, selectors, hirers, among others. At the beginning, the new intake into universities should be merit-based and talented students have to be given seats and showed how to convert the theoretical procedures predominantly on extensive economic growth to the path of greenization. In addition, research conducted at the universities should be funded based on those ideas that have direct relations with greening possibilities as this will encourage talented researchers to develop practical solutions to the pragmatic problems bedeviling society for long time. Many researchers have shown the relevance of a holistic approach to solving the amount energy consumed and dissipated to the environment, which means that, GHRM should keep themselves abreast with the current trends and future prospects as regard green computing.

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