

REVIEW PAPER

Neuromorphic and Sustainable Computing Emergence and Potential Significance in Environmental Sustainability: A Scientific Study

Nilanjan Das^{1*}, Ritam Chatterjee², Abhijit Bandyopadhyay³, Sarmistha Chowdhury⁴ and Mahabubul Hoque⁵

¹ Asst. Professor, Department of Computational Science, Brainware University, Barasat, Kolkata, West Bengal, India

^{2,5} PhD (CIS) Scholar, Department of CIS, Raiganj University, West Bengal, India

⁴ PhD (CIS) Alumni, Department of CIS, Raiganj University, West Bengal, India

³ Principal, Raniganj Institute of Computer and Information Science (RICIS), Raniganj, West Bengal, India

*Corresponding author: nilanjan.das81@gmail.com

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ABSTRACT

Neuromorphic Computing is the recent and emerging computing trends as revolutionary approach in advance technologies invention. Nowadays, computer and computing technologies are transforming in new direction that is more advance and faster than the traditional computing system. Neuromorphic computing is one of the recent emerging computing systems which perform high computational tasks very efficiently with minimum time. This computing system developed by the inspiration from the human brain computation as per human nervous system. As the human can think and take decisions instantly with support of the brain. Neuromorphic computing build with the enormous neural network architectures according to the human brain biological structure. This computing technology has high performance with less energy utilization. Sustainable computing technology is another advance computing system that enable computers to perform task by consuming less energy. In this technological era, power consumption enhances in terms of high computation and increasing utilization of computing systems. Due to the increasing energy consumption and emission of CO₂ and other harmful gases, it is highly recommended to build energy efficient computing system. In this decade, environmental sustainability is main objective to save the world from the environmental depletion. Life in the world is suffering from environmental threats. Due to the increasing dependence of electronic or computing devices, consumption of energy increasing abruptly. Increasing utilization of energy leads environmental impacts on the natures. For the healthy environment required green technologies which helps to make environment friendly technology infrastructure. This

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paper enlightens to the utilization of emerging computing technologies in association with sustainable environment. Neuromorphic computing technology roles in enhancement of green energy emphasized in this paper. This paper also surveys about the sustainable computing nature in connection with healthy environment.

Keywords: Neuromorphic Computing, Sustainable Computing, Neural Network, Environment, Sustainable Environment

Utilization of computing devices including smart electronics gadgets increases regularly in this 21st century. Energy utilization also increases due to the enhancement of computing devices uses. Therefore, enhanced application of computing devices effected to the environmental impact and issues. In this technological era earth facing several challenges regarding environmental issues because there are technological impacts on the environment ubiquitous application of digital technologies extends the demand of energy resources that increase carbon emission in environment. Environment affected with various causes such industrialization growth, growth of transportation, growing of population in the all across the world, and deforestation. Technological growth and electronics computing devices growth are the major challenges in environmental impacts. Emerging technologies including cloud computing, edge computing, fog computing, Internet of Things computing, and another computing implementation growing very fast. 7% of energy consumed by the technological fields in worldwide and it enhances up to 20% by 2025 as per the greenpeace statistics (T. Sangfor 2024).

According to the International Energy Agency (IEA) report data center consumed 200 terawatt-hours electricity for computing demand. Therefore, large amount of energy resource required to fulfil the requirement of the cloud computing data centers. Amazon web services company focuses on the utilization of renewable energy for sustainable development of the cloud computing or green computing platform (Staff, Greenpeace, 2019; Kharchenko, 2013). As the energy demand is growing continuously and it reached high in connection with computing purposes, it is required to make sustainable computing with sustainable computing resources.

Sustainable technologies importance enhances due to the environmental issues and vulnerabilities. Therefore, Green computing or sustainable computing resources become most advance and energy efficient computing resource utilized in every field to develop clean environment (Kharchenko, 2013). Green computing refers low energy consumption which generated through the renewable energy resources (Paul *et al.* 2023). Therefore, green computing has potentialities and benefits for clean and green environment. Green ICT is the another component of sustainable technologies which has implemented to reduce impacts on environment. In this regards neuromorphic computing is the emerging computing technology which may referred as sustainable computing technologies. Neuromorphic computing has the abilities to build energy efficient computing system for sustainable environment. Neuromorphic computing has the applications in different sectors for the computing purposes. But, there is still lack in implementation of neuromorphic computing due to experiments in initial stage. This paper depicts the prospects and significance of the neuromorphic and sustainable computing for clean and sustainable environment. How the neuromorphic computing play role as sustainable computing also depicted in this paper.

Methods

1. Objectives of The Work

This work entitled as “Neuromorphic and Sustainable Computing Emergence and potential significance in Environmental Sustainability: *A Scientific Study*” has the following objectives—

- ❑ To study about the sustainable technologies impact in accordance with sustainable environment.
- ❑ To explore about environmental issues and challenges in connection with the energy consumption and utilization for technological aspects.
- ❑ To know about the ability of the recent computing technologies impact on the environmental issues.
- ❑ To find the relationship between the computing technologies in terms of the environmental barriers.

2. Review of Literatures

Aimone, *et al.* (2022) Neuromorphic computing applied in various purposes to solve complex problems including optimization, image processing and to solve other complex tasks. Neuromorphic computing implemented in solving the tasks for CPU utilization for the solution of graph problem and optimization. Neuromorphic computing is used for non-cognitive application.

Arora, *et al.* (2018) in this decade, environment sustainability is the biggest challenge. Pollution, global warming, and climate changes are the major environmental issues in the world. To overcome the issues of environment degradation, various action taken including green bio technologies implementation. Various microbes are used for the reduction environment pollution, global warming and climate changes.

Burr, *et al.* (2017) advance devices such as Non-Volatile Memory (NVM) is used to apply high energy efficient neuromorphic computing system, spiking neural network, deep neural network is used in implementation of neuromorphic computing and helps to manage energy efficiency. NVM devices associated with neuromorphic computing to process many signals same as human brain process multiple signals.

Paul, (2013) green computing helps to reduce power consumptions. Green computing is very essential in environment sustainability. Cloud computing as well as green computing both technologies are associated in enhancement of sustainable environment. Green computing and cloud computing technologies adopted in every sectors for the enhancement of green technology infrastructure.

As there are few works has been conducted of implementation of neuromorphic computing for the sustainability of environment, this work focuses on the implementation of neuromorphic and sustainable computing in environment.

3. Research Question

This work entitled as “Neuromorphic and Sustainable Computing Emergence and potential significance in Environmental Sustainability: *A Scientific Study*” has been prepared based on the emerging computing technologies roles in environmental sustainability. This work is based on the theoretical aspects. Various information gathered from secondary sources including journals, website contents, book chapters, etc. This article based on following research question.

- RQ1: What are the issues and challenges in environmental sustainability according to the computing?
- RQ2: What is the significance of sustainable computing?
- RQ3: What are the roles of sustainable computing in respect of environment sustainability?
- RQ4: What are role of Neuromorphic Computing in environmental sustainability?

RESULTS AND DISCUSSION

Issues and Challenges of Environment in Context of Computing

Increasing greenhouse gas emission and increasing temperature of earth surface are prime challenges in this decade. There are various reasons to enhance the issues in environment. Environment depletion causes are the increasing fuel consumption and carbon emissions regarding transportation and mobility. Pollution, climate changes, global warming, loss of biodiversity are the major challenges in environment. High energy demand increases fossils and fuel burning and enhance the carbon emission which directly affected on the environment^[4]. Therefore, increasing non renewable energy sources utilization generate environmental challenges. Energy dissipation raised very high according to the extended use of the digital technologies. As per the statistical report of Global Carbon Budget Project, globally CO₂ emission reached at 41.6 billion tones by 2024^[34]. Temperature raised very high in the year 2024 by the WMO State of Climate update report^[34]. This report is the alarming for every state and countries environment in the world. Power consumption rate is increased in every year by average rate 3.4% up to 2026 according to the International Energy Agency (IEA) report^[16]. Technologies progress and hike of smart electronics gadgets intensify the power consumption. Electronic computing devices such as mobile phone, computer, cloud data centers, servers, IoT sensor devices, cloud edge devices etc. are consumed more energy for processing purposes. Table 1 shows the utilization of energy by emerging technologies in this era.

Table 1: Power Consumption of Computing System

Computing System	Impacts
Personal Computing	Power consumption enhanced due to the increasing uses of personal computing.
Cloud Computing	Data centres power consumption rise high by 2026 ^[34] .
Artificial Intelligence	Artificial Intelligence power consumption may raise high by 2026 ^[34] .
Block Chain	Block Chain power consumption may raise high by 2026 ^[34] .

Sustainable Computing and its significance

Sustainable Computing is a technology based computing procedure to minimize the electronic waste and maximize the sustainability. Sustainable Computing is a conceptual framework that is applicable throughout the life-cycle of a product like designing development, utilisation, reuse and proper disposal. The main objective of Sustainable Computing is to perform any task with less utilization of energy and generates less amount of carbon footprint.

Sustainable Computing has a great environmental responsibility. To protect our environment. It is necessary to adopt the Sustainable Computing Technologies in every fields and sectors. One of the important significance is to integrate the Sustainable Computing Technology, is to maintain the energy efficiency^[11]. Energy is one of the basic element to operate any device. It requires to design new types of hardware that

uses less amount of energy to operate. It also suggests to use low power and energy efficient electronic devices that have higher number of energy star rating. It requires to design automatic software that are able to manage the power consumption and sleep mode enabled facility that are helpful when the devices are not in use and it should be switched off automatically. The digital world dependent on the data. So it is necessary to store large volume of data to provide different facilities to the user. For the Physical storage of the data, it is necessary to establish different types of data centres. To operate the data centres requires huge amount of energy. So to implement the Sustainable Computing, it is necessary to reduce the power consumption by the data centres. It is recommended to use renewable energy to operate the data centres. It is necessary to use energy efficient cooling system for the data centres.

Sustainable Computing encourages the use of cloud computing Technology for the low power consumption by the servers. Instead of data storing in the local server, the Sustainable Computing suggest to store the data in the cloud server. Cloud Computing provides the data virtualization. It is very helpful to maintain the data privacy and the security. The use of cloud computing reduces the overhead for the maintenance of the data storage cost and the cyber security cost.

Electronic waste are one of the challenging task to handle. The unplanned disposal of e-waste create environmental pollution. To maintain the sustainable development, it encourages to reduce the e-waste generation and the proper procurement of the e-waste^[3]. It is highly encouraged to re-think, reuse, reduce and recycle the e-waste. It is also necessary to proper disposal of e-waste.

Sustainable software engineering plays a vital role to implement Sustainable Computing. At the time of planning to build the system, it is necessary to think about Sustainable Computing. On the basis of proper planning and good decision making the system should be designed. At the time of building the software it is necessary to keep in mind to minimal utilisation of different resources like CPU, memory, storage, different types of peripheral devices and networking devices. It is important to use different types of hardware devices that running in low power. It is necessary to integrate different types of Internet of Things (IoT) enabled sensor based system to minimal utilisation of energy.

The main objective of utilizing the Sustainable Computing is that it has a great environmental impact. As it utilizes low amount of energy for the execution of the system, it save the carbon footprint that can be generated to produce the energy. Sustainable Computing encourages the use of renewable energy, thus it promotes green Computing. Decreasing our reliance on paperwork directly translates to a decrease in the number of trees needed to produce that paper. Sustainable Computing helps in resource conservation. Bhai proper management of e-waste and the recycling of electronic waste helps to restore different types of material and that are used in new product generation. One of the major benefits of Sustainable Computing is its economic benefit. By saving energy means it saves the cost of the electricity bill. By implementing paperless system, reduces the purchasing cost of the paper. By storing the data digitally, reduces the data storage cost. With the use of high efficient, high star rating with low energy consumption devices means less consumption of energy. That also helpful in reduction of cost. Sustainable Computing also plays the major roles to carry out corporate responsibility and to implement different types of sustainable Development modelling.

Roles of Sustainable Computing in the environment

Sustainable Computing plays a vital role to protect the environment. It encourages the minimization of greenhouse gas emission. Greenhouse gases create many the problems, so the reduction in greenhouse gas

is very effective to protect our environment. The utilization of renewable energy promotes the Sustainable Computing. The utilization of renewable energy to fulfil the energy requirement is highly encouraged because it reduces the carbon footprint. One of the main focus of Sustainable Computing to use less number of resources to complete a task. Less number of resources use means reduction of energy demand that also implies less generation of carbon footprint. Reduction in energy consumption is one of the primary focus of Sustainable Computing. It is necessary to upgrade the hardware and software on a regular basis. The electronic devices should have higher number of energy star rating and less use of energy.

One of the major challenge of Sustainable Computing is to manage the e-waste. The management of e-waste is necessary to maintain the sustainable development. It is necessary to minimize e-waste generation. It is necessary to extend the device life cycle. Before purchasing a new electronic device, it is recommended to re-think. It is encourage to repair and reuse the electronic devices. To mention the sustainable development, it is also necessary to adopt proper e-waste disposal plan. Sustainable Computing encourages the smart manufacturing. It plays a vital role in energy efficient manufacturing. The Sustainable Computing is deal with the conservation of the natural resources.

One of the major role of Sustainable Computing in environment, is to conserving the natural resources. By the use of different types of Technologies, it helps to minimize the use of natural resources that are used as raw material. It reduces the use of paper by the use of Green Computing in every aspect. The Sustainable Computing also saves the energy by the use of energy efficient manufacturing, so it reduces the emission of carbon footprint. With the implementation of different types of algorithms that are help in efficient Energy Management. The Sustainable Computing algorithms are designed for the mass utilization that minimize the use of paper and help to reduce the pollution. Different types of sensors used in sustainable Internet of Things (IoT), helps to get more accurate real time data. The sensors based system gives the power of automation.

Sustainable Computing promoting the Digital Sustainability. It uses different types of Artificial Intelligence and Machine Learning based algorithms to serve the better result. It provides efficient telecommunication system and remote monitoring system. The fully automatic system helps to manage advance circular economy. It extends the product life cycle. By the use of different Artificial Intelligence based algorithms, it manages an efficient supply chain. From the smart manufacturing to smart delivery with less use of energy. Sustainable Computing plays a vital role in environment monitoring. It has the crucial role in Environment protection. By the use of different types of conservation Technology it minimise the carbon footprint. By considering different climate based modelling it have designed its algorithm to protect the environment. Fig. 1 describes different components of sustainable computing and its resources.

Foundation of Neuromorphic Computing and Its Application

Neuromorphic computing is the efficient computing technique which is developed as followed with the structure and functionality of human brain. Neuromorphic computing is the recent computing technology revolutionary approach to improve the computing speed and efficiency^[1]. Neuromorphic computing developed in accordance with neurons and synapse that create neural network to compute or perform the tasks. Neuromorphic computing perform the processing of task using artificial neurons^[6].

As the neuromorphic computing is inspired on the neuron structure of human brain, it is complex to develop neuromorphic computing. Neural network is also artificial neuron structure inspired from human neuron

structure and biological neuron functionalities are applied in the artificial neural network for development of computing system which give the facilities to process large tasks efficiently. Neuromorphic computing build with advance artificial neural network which referred as spiking neural network^[17]. Spiking neural network is different from the traditional artificial neural networks. It is advance structure of artificial neural network. Research on neuromorphic computing highlights new direction in advance computing system. Neuromorphic computing discovery is the recent Artificial Intelligence (AI) innovation in advance computing system.

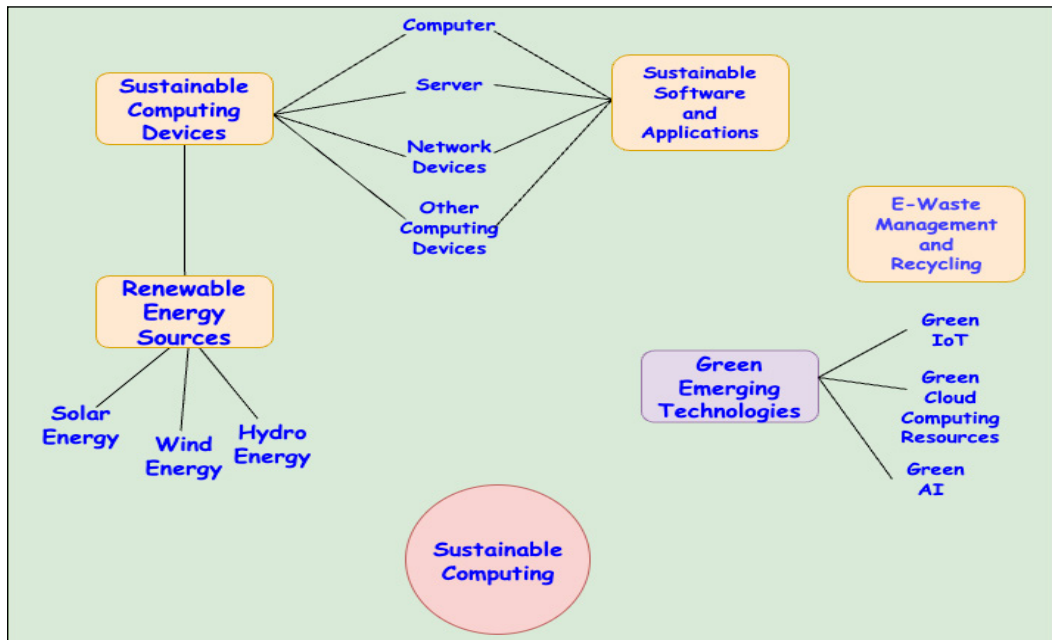


Fig. 1: Components of Sustainable Computing

Units or hardware of computer system developed with neuromorphic computing approach that process large information. AI based artificial neural network algorithms models utilize to accomplished computational tasks. Vast neurons are connected to perform the mammoth of data processing tasks without high energy consumption.

Neuromorphic computing is applicable in the fields of robotics, healthcare, remote sensing, self-driving cars, smart devices. Research and experiments are continuing to develop and apply the neuromorphic computing in different aspects. Neuromorphic computing has the significant prospects in different domain for improvement of computing system. Neuromorphic computing devices manufactured and designed by the IT companies. IBM, Intel and other companies are experimenting to build energy efficient and powerful AI based hardware system. Following are some invention and experimental development of the neuromorphic computing system. Table 2 describe about the recent development of the neuromorphic devices or processors by the IT companies.

Table 2: Neuromorphic Computing Invention and Development

Organizations	Applications	Functionalities
IBM	NorthPole	North pole is the chip based on neuromorphic computing system. It is the updated version of True North. It is 25 time more energy efficient and faster processing capabilities than other ^[23] .
IBM	TrueNorth	True North is the neurosynaptic chip based on neuromorphic computing system. It is more energy efficient and faster than other ^[2] .
Intel	Loihi 2	It is aneuromorphic processor developed by Intel which is 10-time faster processing efficiency. Artificial Intelligence technology applied with integration of hardware to made this efficient neuromorphic processor ^[17] .
BrainChips Holding Ltd	Akida	Neuromorphic AI based processor. It is most efficient and energy saving processor ^[9] .

Role of Neuromorphic Computing in Context of Sustainable Computing and Environmental Sustainability

Neuromorphic Computing is the advance version of the sustainable computing. Nowadays sustainable technologies invention and transformation enhanced continuously. As the sustainable computing widely accepted, neuromorphic computing also adopted to make sustainable computing environment. Neuromorphic computing can change the computing techniques that enhance the efficiency as well as solve the environmental concerns. Neuromorphic computing is most advance AI application which is more energy efficient computing system. Recent modernization of the microprocessor and processor designed as neuromorphic computing are energy efficient. Therefore, neuromorphic computing processor consume less power than traditional computing^[22]. Hardware and devices are designed in the way for the neuromorphic computing with neuromorphic algorithm to develop energy efficient computing. Global warming, climate changes are major environmental concerns today due to the raised energy demand. Therefore, energy efficient system is required to save the life in the earth from the rising environmental issues. As sustainable or green computing is the energy efficient computing system which has direct impact on the environment sustainability. Fig. 2 shows the integration of hardware and Artificial Intelligence Technology in Neuromorphic Computing System.

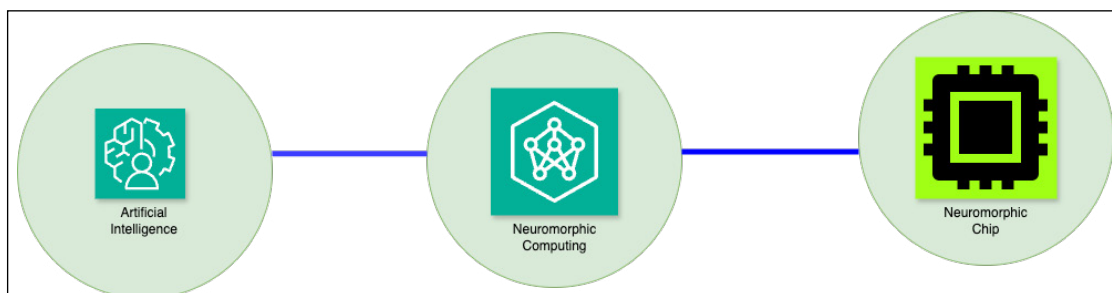


Fig. 2: Neuromorphic Computing System with The Integration of Hardware and AI

Core Findings and Suggestions

In this study, neuromorphic computing and sustainable computing applications, features, potentialities

and significance in connection with energy efficiency and performance incorporated with the following suggestion and views—

- ❑ High energy utilization raised continuously as technologies significance enhances in this recent era.
- ❑ Sustainable computing being the part of sustainable technologies which has impact in consumption of less energy. Therefore, sustainable computing give support to minimize the utilization of energy that directly minimize the environment depletion.
- ❑ Experiments and invention are carried on to build advance computing technological system which will be faster, efficient and sustainable in nature.
- ❑ Sustainable computing and sustainable technologies have potentialities and necessities to make environment more sustainable.
- ❑ In the views of environmental challenges advance technologies are essential to build up environment friendly green technologies.
- ❑ Therefore, it is required to implement robust policies and administrative strategies to develop more green technologies and advance sustainable computing system to make sustainable environment.
- ❑ Awareness required to understand the actual requirement and significance of sustainable computing as well as neuromorphic computing efficiency for the environment sustainability.

CONCLUSION

To save the earth from environment degradation, sustainable environment required to be built up to ensure environment friendly future in earth. The energy demand is increasing regularly in the world, due to the digital technology revolution. Raised energy requirement effect on the environment that enhance the energy production by emission of carbon gases in the environment. Sustainable computing and technologies are useful to save the environment from depletion. Sustainable computing and neuromorphic computing become part of environment sustainability. Therefore, sustainable computing built with green technologies. Neuromorphic computing implements powerful computing that utilize less power for computing. As the AI continuously advancing in this technological era, neuromorphic computing has the future prospects. Meanwhile, neuromorphic computing is growing field and is applicable in development of faster energy efficient computing system.

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