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Review Article

An Overview of Green Computing for Smart Energy Management

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Abstract

Surging power demands across modern data centers and high-performance computing (HPC) architectures present major economic and ecological challenges, highlighting the urgent need for intelligent, sustainable energy management solutions. Green computing addresses these issues by deploying interconnected computational resources operating on standardized communication protocols to balance energy supply with dynamic workload demands. By utilizing heuristic scheduling, live migration strategies, and resource allocation algorithms, green computing minimizes power consumption, optimizes server performance, and reduces reliance on hazardous materials. This special issue overview examines recent interdisciplinary advancements that integrate Knowledge Engineering, mathematical modeling, big data analytics, and artificial intelligence into green computing frameworks. The compiled research covers a broad range of applications, including heuristic secure routing protocols for network energy efficiency, data mining for atmospheric pollution monitoring, digital twin simulations in the new energy vehicle sector, Bayesian risk modeling in energy finance, and AI-driven supply chain optimization. Empirical findings across these studies demonstrate significant quantitative benefits, such as reduced latency, improved prediction accuracy, extended network longevity, and enhanced resource utilization rates. Ultimately, this collection proves that combining green computing principles with advanced digital technologies provides a robust foundation for effective environmental governance, grid resilience, and sustainable economic growth.

Keywords

Green computing, Smart energy management, High-performance computing, Data centers, Artificial intelligence, Security routing protocol, Sustainable energy, Digital twin technology

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1. Introduction

Green computing comprises networked computing infrastructures operating via standardized communication protocols to fulfill energy demands across smart environments. Escalating energy consumption faces increasing risks due to volatile pricing, power availability constraints, and associated ecological impacts. The surging power demand within data centers and high-performance computing (HPC) facilities represents a critical concern, highlighting the urgent necessity to construct efficient, intelligent frameworks that mitigate undesirable environmental consequences. Within high-performance computational architectures, Green Computing addresses a multi-tiered challenge of balancing concurrent power demand with server-to-datacenter energy distribution. It dynamically adapts workload assignments to individual servers to satisfy stringent energy constraints.

As a foundational field of study, Green Computing plays an essential role in smart energy management. Heuristic green computing algorithms emphasize live migration methodologies aimed at minimizing power consumption through dynamic server scheduling based on sequential search, random search, and maximal fairness in resource allocation.

Contemporary advances in smart technologies seek to combine Knowledge Engineering with mathematical modeling capable of operating, managing, integrating, and reasoning alongside Green Computing principles to foster an energy-efficient environment. This special issue compiles key peer-reviewed contributions addressing these essential objectives, specifically focusing on raising energy efficiency and lowering the usage of hazardous materials.

2. Literature Review

2.1. Heuristic Green Computing for Energy and Security Optimization

In the paper titled "Heuristic Green Computing Based Energy Management with Security Enhancement Using Hybrid Greedy Secure Optimal Routing Protocol", the authors present an novel energy management framework combined with a security enhancement scheme based on heuristic green computing and an optimized routing protocol. Energy management within green computing is implemented to boost overall network energy efficiency using heuristic strategies. Furthermore, a rigorous security evaluation was conducted to facilitate secure data transmission across the network using the Hybrid Greedy Secure Optimal Routing Protocol (Hy_GSOPRP). Simulation results demonstrate that the proposed routing method significantly outperforms existing protocols, achieving a Mean Absolute Percentage Error (MAPE) of 62%, a Mean Loss Rate (MLR) of 55%, a Root Mean Square Error (RMSE) of 45%, a reduction in energy consumption of 59%, an extension in network lifetime of 95%, a delay reduction of 40%, and a throughput improvement of 98%.

2.2. Atmospheric Pollution Assessment via Data Mining

In the study titled "Application of data mining combined with power data in assessment and prevention of regional atmospheric pollution", the authors examine the requirements of atmospheric environment data mining while continuously monitoring and controlling regional atmospheric pollution. By utilizing real-time detection and evaluation of the regional environmental pollution index, timely intervention can be triggered whenever atmospheric pollution exceeds allowable standards. Experimental results show that prediction accuracy was improved by 4.18%, accompanied by a measurable drop in the overall environmental pollution index. Furthermore, the rate of atmospheric environmental quality scores increased by 2.38%, and the overall control effect was optimized by 3.1%, proving that data mining combined with power data significantly enhances regional air pollution prevention.

2.3. New Energy Technology Innovation and Economic Sustainability

In the article titled "New energy technology innovation and sustainable economic development in the complex scientific environment", the authors explore the relationship between energy technology innovation and long-term economic sustainability by evaluating the features, structural components, and practical obstacles of New Energy (NE) technology innovation. Implementation strategies were tailored to the current realities of the NE industrial sector. Following technology innovation in complex environments, resource utilization rates, energy system completeness, and economic returns were substantially higher than pre-innovation levels. Specifically, resource utilization improved by 12.3%, the degree of energy system perfection increased by 9.4%, and economic benefits rose by 9.4%, demonstrating a robust positive correlation between energy innovation and economic sustainability.

2.4. Mathematical Modeling of Renewable Energy Growth Trends

Through empirical experiments and algorithmic designs presented in the paper titled "Evaluation of dynamic growth trend of renewable energy based on mathematical model", the practical utility of mathematical modeling in capturing dynamic growth trends in renewable energy was demonstrated. The findings reveal that mathematical model analysis delivered a 24.8% performance improvement in forecasting and understanding dynamic renewable energy growth trajectories.

2.5. Digital Twin Technology in the New Energy Vehicle Industry

The defining characteristic of digital twin technology lies in its capacity to dynamically simulate physical systems, including applications in the automotive sector. In the research titled "Research on collaborative innovation of key common technologies in new energy vehicle industry based on digital twin technology", the authors analyze patent filing trends, the automotive sector's reliance on oil, and production and sales metrics across two vehicle categories facing key technological bottlenecks. Results indicate that integrating digital twin technology supported an annual production growth of 9.22% and an annual sales growth of 9.18% in new energy vehicles.

2.6. Optimal Planning of Modern Power Systems with DGs and EVs

In the paper titled "Review on optimal planning of new power systems with Distributed Generations and Electric Vehicles", the physical characteristics of next-generation power grids are systematically summarized. The study assesses how integrating Distributed Generation (DG) and Electric Vehicles (EVs) impacts overall grid planning. Based on a review of existing planning models, key technical hurdles are analyzed across control strategies, power flow computation, uncertainty management, network expansion, and equipment planning. Finally, four strategic future directions are proposed: inter-system dependencies, diverse EV charging demand responses, grid resilience enhancement, and comprehensive planning evaluation.

2.7. Petroleum Financial Risk Early Warning via Bayesian Networks

In the study titled "Energy financial risk early warning model based on bayesian network", historical financial risk data covering oil markets from 1987 to 2015 were analyzed using Bayesian networks and Back-Propagation (BP) neural networks. While BP neural networks yielded a 65% correlation between predicted and actual risk profiles, the Bayesian network demonstrated superior fitting performance, achieving a success rate of up to 80%. By leveraging auto-regressive movement and time-series measurements, the Bayesian network exhibited high model reliability, confirming its value for early risk warning in energy finance.

2.8. Comparative Analysis of Energy-Based Hydro-Sediment Models

In the work titled "Comparison of two hydro-sediment models based on energy principle of water movement in saturated/unsaturated soils", two physics-based models—CASC2D-SED (CASCade 2 Dimensional SEDiment) and GSSHA (Gridded Surface Subsurface Hydrologic Analysis)—were applied to simulate runoff and sediment dynamics in a semi-arid watershed on the Loess Plateau. Grounded in mass and energy conservation principles, both models yielded closely aligned conclusions regarding rainfall infiltration and silt transport. Evaluating major flood events between 1981 and 2017 across three distinct historical periods showed satisfactory performance, with average Nash-Sutcliffe efficiency coefficients of 0.81 for runoff and 0.70 for sediment. GSSHA achieved higher precision in modeling maximum and total runoff/sediment amounts (relative error improvements of 6.8% for peak flow, 8.6% for runoff depth, and 6.7% for peak sediment). Conversely, CASC2D-SED yielded better temporal accuracy for peak discharge and peak sediment timing, showing mean lead differences of 0.27 and 1.02, respectively.

2.9. Digital Landscape Design for Green Wetland Ecology

The paper titled "The digital landscape design and layout of wetlands based on green energy and ecology" investigates landscape layout strategies using green ecological principles as a foundation and digital tools as a driving force. The research formulated core concepts including the integration of biodiversity protection with scientific plant placement, water purification combined with plant community diversity, and ecological functionality with recreational space. Utilizing 3D Max, Grasshopper, and ArcGIS parametric software, 3D digital simulations of plant community landscapes were achieved. The resulting wetland landscape layouts proved vivid, accurate, and highly efficient, aligning cleanly with sustainable green ecological concepts.

2.10. Groundwater Protection and Energy Efficiency via Big Data & IoT

In the article titled "Groundwater development and energy utilization of water environment protection based on big data and Internet of Things", current groundwater resource usage patterns in China were evaluated to address groundwater energy efficiency and environmental protection challenges. Findings indicate that prior to 2017, energy utilization rates remained low while water pollution levels peaked at 92%. Following the adoption and maturity of IoT big data technologies starting in 2018, energy efficiency improved across all region types, water pollution levels dropped to historic lows, water source quality improved, and public satisfaction with groundwater development and environmental protection reached 96%.

2.11. AI-Driven Economic Resilience Assessment in Energy Sector

In the paper titled "Evaluation on the impact of digital transformation on the economic resilience of the energy industry in the context of artificial intelligence", the authors developed a Particle Swarm Optimization-based Least Squares Support Vector Machine (PSO-LSSVM) model. Empirical tests show that the proposed framework accurately predicts the economic resilience index, achieving a post-training average prediction error of just 0.0028. Compared to standard LSSVM and BP neural network baselines, this approach provided greater stability and superior predictive accuracy.

2.12. Groundwater Risk Assessment in Abandoned Mining Regions

In the investigation titled "Groundwater risk assessment of abandoned mines based on pressure-state-response- the example of an abandoned mine in southwest China", environmental risks were evaluated using the Pressure-State-Response model. Results highlighted high groundwater environmental risks in studied areas, with southeastern zones exhibiting higher risk indices than northwestern zones. Heavy metals and toxic contaminants carried by Acid Mine Drainage (AMD) were shown to infiltrate surrounding water systems, posing direct health risks to downstream populations. These findings provide theoretical grounding for regional mine remediation and offer a reference framework for environmental risk assessments in active and abandoned mining sites.

2.13. Low-Carbon Garden Landscape Design Driven by Big Data

The paper titled "Landscape design of garden plants based on green and low-carbon energy under the background of big data" proposes a low-carbon garden design framework using big data analytics. The paper analyzes energy efficiency issues and presents Data Envelopment Analysis (DEA) to guide site planning, plant selection, and material choice. Experimental results confirmed that low-carbon urban landscaping substantially lowered net carbon emissions; green space carbon sequestration increased from 303,089.26 to 335,757.06 (a net gain of 32,667.8 units), confirming the practical ecological benefits of low-carbon landscape design.

2.14. Biomass Energy Conversion in Cadmium-Contaminated Soils

In the research titled "Method of improving the conversion of cadmium-containing plant biomass energy under the background of soil pollution", the growth dynamics of rape and sunflower under varying Cadmium (Cd) stress levels were analyzed. Parameters including plant height, root/aerial dry weight, chlorophyll, and proline content were measured. Results indicated that low Cd concentrations (0–10 mg/kg) promoted plant growth, whereas higher Cd concentrations progressively reduced height, dry weight, and chlorophyll content. Introducing biochar, Bacillus subtilis, and earthworms improved germination rates and enhanced biomass energy conversion efficiency in Cd-contaminated plants.

2.15. Bimetal 3D Printing for Copper Alloy Shell Remanufacturing

In the article titled "New process for integrated manufacturing of copper alloy shells by bimetal 3D printing remanufacturing technology", single and bimetal 3D printing technologies were evaluated to construct 3D models of copper alloy water meters. Experimental analysis showed that increasing sintering temperatures enhanced sample density due to tighter bonding among copper powder particles. Remanufacturing integrated copper alloy shells via bimetal 3D printing adjusted density, thermal conductivity, dynamic viscosity, and solid-phase ratios under set thermal conditions, granting higher plasticity and thermal conductivity while expanding the industrial applicability of alloy materials.

2.16. Multi-Sensor Data Fusion for Flowmeter Network Security

The paper titled "Information security of flowmeter communication network based on multi-sensor data fusion" examines cyber security across flowmeter networks using multi-sensor data fusion and artificial intelligence. The authors introduce network security principles, present a cloud computing-based security situation prediction algorithm using cloud models, and propose a complete network security assessment architecture. Experimental outcomes underscore the high resource utilization, uniform standards, and broad applicability of intelligent flowmeter processing systems, while stressing the urgent need for robust security frameworks across technical, legal, managerial, and personnel dimensions.

2.17. AI-Based Electric Load Unloading in Smart Sports Stadiums

In the paper titled "Coordinated distribution of stadium electric load unloading based on artificial intelligence", a novel Smart Stadium AI (SE-AI) methodology was introduced to enhance control capabilities across stadium functional zones. The model enables integrated management of electrical equipment based on engineering design principles. Advanced technological integration moves stadium power systems toward higher digitalization, intelligence, and operational efficiency.

2.18. Social Governance and AI in Energy-Oriented Cities

Sustainable urban development requires effective energy management. In the paper titled "Analysis of social governance in energy-oriented cities based on artificial intelligence", AI techniques mimicking human cognition were deployed to support municipal decision-making. Applying AI within urban energy management enables authorities to make ecologically sound decisions while strengthening data security through social governance (SG). The combined SG-AI framework effectively streamlines energy administrative tasks and shortens project execution timelines.

2.19. Automotive Supply Chain Pricing and Coordination with Charging Facilities

The study titled "Pricing and coordination of automotive supply chain for incorporating efficient charging facilities" models a dual supply chain containing manufacturers and retailers for both new energy vehicles (NEVs) and traditional vehicles. Comparing pricing, demand, and profit under centralized vs. decentralized decision-making led to the design of a novel contract mechanism combining revenue sharing with ex-factory price negotiation. When contract parameters satisfy specific conditions, the mechanism coordinates the supply chain and increases profit for all participating stakeholders. Further analysis confirmed that expanding charging facility infrastructure positively influences vehicle pricing, market demand, and total supply chain profitability.

2.20. AI Algorithms for Financial Risk Warning in International Energy Trade

In the paper titled "Service risk of energy industry international trade supply chain based on artificial intelligence algorithm", three AI algorithms—artificial neural networks (ANN), genetic algorithms (GA), and particle swarm optimization (PSO)—were applied to evaluate financial service risks in energy trade supply chains. An early warning model was built and validated experimentally. Results showed that the AI-driven risk early warning system helped banking institutions improve corporate credit assessment accuracy by 7.43% and information gathering accuracy by 5.61%. Additionally, external environmental risk forecasting accuracy improved by 3.52%, while bank operational risk and legal/regulatory risk were reduced by 6.58% and 7.06%, respectively.

2.21. Machine Learning for Hydrocarbon Accumulation Prediction in Sichuan Basin

In the paper titled "The division of oil and gas accumulation assemblage in Sichuan Basin and the construction of favorable accumulation prediction mode", machine learning techniques were implemented to classify oil and gas accumulation combinations and predict favorable target zones. The proposed prediction model was benchmarked against traditional prediction methods. Test results revealed that average relative errors for sample wells No. 1, 2, 3, and 4 in the proposed machine learning model were 23.33%, 24.93%, 26.38%, and 22.60%, respectively, compared to higher errors of 26.19%, 32.37%, 36.16%, and 27.87% in conventional models. These findings confirm the superior accuracy of machine learning frameworks over traditional geological prediction models.

3. Conclusion

Sustainable development and efficient smart energy management are achievable only through effective integration of green computing, artificial intelligence, mathematical modeling, and digital twin technologies. The articles collected in this special issue demonstrate substantial quantitative advancements across dynamic server scheduling, air pollution monitoring, new energy technology adoption, power system planning, financial risk early warning, and supply chain optimization. Together, these interdisciplinary methodologies establish a solid foundation for energy efficiency, reduced environmental impact, and intelligent resource governance in modern energy ecosystems.

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Conflict of Interest

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