

Chapter 12: Sustainable Design and Energy Optimization in Cloud-Enabled Smart Technologies

12.1. Introduction to Sustainable Design

A sustainable city is one designed with consideration for environmental impact, inhabited by people dedicated to minimizing the required inputs of energy, water, and food, and waste output of heat, air pollution—i.e., CO₂, methane—and water pollution. The idea behind it is simple: design towards efficiency and enable humanity to coexist symbiotically with nature. Sustainable development is often defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The term sustainable is used to describe the different activities that aim toward sustainability. Sustainable design considers the potential environmental impact of building materials over their entire life cycle. Sustainable development is the process through which sustainability is achieved. There are different paths leading to sustainability: stable ecology, dynamic equilibrium, working in cycles, living within limits and carrying capacity, appropriate technology and self-reliance, less energy utilization, utilitarianism, and environmental modification. Sustainable development is a continuous, repetitive process aimed at protecting natural resources and improving human life without harming people. It is a process that makes optimum utilization of natural resources; this is necessary for life to be lived in better conditions. Sustainable development is a balanced growth of all factors—population, capital, technology, and resources—achieved by using existing resources efficiently and expanding new resources in turn.

12.1.1. Understanding the Fundamentals of Sustainable Design

For a long time, the concept of “sustainable design,” defined by The Brundtland Commission Report as design that meets the needs of the present without compromising

the ability of future generations to meet their own needs, has attracted great attention from many stakeholders across several study fields. In the area of “design” and “energy,” the passion for reducing the consumption of non-renewable energy resources and optimizing energy efficiency and performance has led researchers to create a wide range of methods, techniques, execution, and methodologies aimed at analyzing and proposing appropriate energy usage. The concept of sustainability also plays an increasingly important role in modern architecture as it is characterized as a comprehensive approach toward protecting the environment. Designers have conveniently entered a world of sustainable design that aims to minimize the use of non-renewable energy.

When dealing with the idea of sustainability, the topic of cloud-enabled smart technologies arises. This phase is associated with the delivery through the cloud of business processes, applications, infrastructure, and embedded device services. These phases are mature areas in today’s smart cities community, but still need much attention regarding their focus on energy usage, efficiency, and performance. Such issues have been studied extensively in the literature on grid computing, cloud computing, grid enabled scientific applications, and cloud enabled commercial applications, but recent studies focus more on the routing, security, and HPC in cloud computing environment. Therefore, special attention needs to be paid in the smart city context to sustainable cloud-enabled smart technologies; indeed, the adverb sustainable describes directly the consumption of non-renewable energy resources by cloud-enabled smart technologies and especially their energy efficiency and performance.

12.2. Overview of Cloud-Enabled Smart Technologies

Cloud-Enabled Smart Technologies. Cloud-enabled smart technologies are based on the integration of the Internet of Things (IoT), smart environments, and cloud computing. IoT facilitates the interconnection of embedded objects through complex networks, transcending the connections between wireless object networks that characterize wireless sensor networks [1-3]. The development of an IoT network enables the establishment of smart environments via the deployment of sensing devices. The availability of administrative and technical cloud services supports the supply chain with the delivery of necessary on-demand resources. The main role of cloud computing is to provide elasticity services, allowing customers to utilize an arbitrary number of resources instantaneously, paying only for the resources used.

Research has shown that the joint contributions of all three factors allow the implementation of sustainable design. According to the Sustainable Development Strategies Group (SDSN), a sustainable design is a universal process capable of generating solutions to guide human progress toward more resilient living styles, particularly in urban areas. These urban enclaves are generally subject to issues such as

transport, energy and water availability, air pollution, and waste management. The strategic role of Big Data approaches is to classify problems or hazards in the service period, while cloud-enabled smart technologies offer the appropriate kind of service or resources needed to solve the problem.

12.2.1. Exploring Cloud-Enhanced Intelligent Solutions

Sustainability in Industrial Development sectors is provided by integrating advanced technologies with agriculture, a bridge between advanced scientific methods and untouched agricultural resources. Managing the environment efficiently through new techniques is one goal. Smart Agriculture is one such area using Information and Communication Technologies. Cloud computing is a platform that provides resources and services such as Data Storage, Software, Infrastructure, Platforms, Networking, Security, Bandwidth, Remote Access, etc., through the Internet based on the pay-per-use model. Cloud services utilize the software-as-a-service model. Cloud computing offers virtualized resources on a pay-per-use basis. Communication-oriented computing (COC) is a practical model for delivering cloud services provided by different physical resources distributed in multiple geographic locations to meet diverse customer requests. {>} {->}



Fig 12 . 1 : Sustainability in Industrial Development: Smart Agriculture, Cloud, COC, and Data Protection

A new scheduling algorithm based on data transmission time and current workload of the communication network can reduce service completion time and reduce carbon dioxide emissions. Sensitive data protection is a challenging issue in cloud-enabled smart technologies, with data hiding an essential technique that requires lower power consumption in resource-constrained devices. Low-power data hiding is a promising approach for privacy preservation in cloud-enabled smart technologies such as smart home, mi-tag, smart grid, and smart healthcare systems. Gigantic Smart Cities are connected and managed through sensors linked to the Internet of Things (IoT) devices, where flexible and efficient storage of the enormous data generated by these devices is required. Integrating IoT with cloud computing enables storing, managing, and analyzing data produced by these connected devices.

12.3. The Importance of Energy Optimization

Sustainable design addresses environmental impacts, focusing on reducing waste, pollution, and loss of natural resources and biodiversity. It enables future generations to meet their needs while satisfying present requirements. Recently, ideas of resource efficiency and life cycle assessment have become central topics in discussions about green approaches in design. Cloud-enabled smart technologies offer services in everyday life, supporting decision-making and enhancing quality of life. These evolving technologies provide convenient, efficient, intelligent public services by enabling real-time detection of public safety and environmental conditions.

The continual demand for bigger, faster, and better services in cloud computing results in intensive use of physical machines in cloud data centers. This leads to high energy consumption and undesirable carbon footprints, which cannot be neglected. To alleviate these environmental consequences, the development of a green cloud structure is imperative. Additionally, smart grid and smart transportation can be implemented to satisfy energy demand, provide the best routes, and resolve problems related to energy storage and demand response.

12.3.1. Strategies for Effective Energy Management

Effective energy-management strategies are pivotal in shaping a sustainable future. Firstly, demand-management strategies aim to avoid an undesirable growth of peak demand caused, for instance, by the proliferation of electrical appliances such as heating/cooling systems for residences, cars powered by electricity, and electric transport systems. Demand-response programs target peak reduction and flexibility through the active involvement of end-users whose assistance is required in periods of considerable stress on the energy system (e.g., in times of extreme hot or cold weather).

Secondly, energy storage management can contribute to the sustainability of the energy system by allowing energy to be stored during off-peak periods and released when it is required. Efficient storage devices can deliver various services to support the system, such as reducing the demand for peak power and providing tertiary frequency control.

12.4. Principles of Sustainable Design

Environmentally sustainable design focuses on minimizing native habitat disturbance and the often considerable environmental impact generated by the production, operation, and ultimate disposal of smart technology. Important factors affecting smart technology include its carbon footprint, i.e., directly or indirectly produced greenhouse gases, energy use, water use, and pollution. These factors must be analysed throughout the device lifecycle – from developer through manufacturer, purchaser, and end user.

A common purpose of smart technology is reducing the societal impact of resource consumption. For example, cloud-enabled smart connected products can reduce society-scale use of water, fuel, materials, and electrical energy. When designing such technologies, a tradeoff arises between the scarcity and cost of resources consumed by the smart technology itself and societal-scale enabled savings. Ideally, society-scale resource savings provided by smart technology justify the use of scarce resources inside the technology.

12.4.1. Life Cycle Assessment

A Life Cycle Assessment (LCA) of an active, well-known smart city – Masdar City – determines the heterogeneous damage caused by the United Arab Emirates (UAE) in terms of economics, environment, and human health. Although these two aspects are crucial and deeply related, it is a mistake to assume that the only goal of smart city development is to reduce the environmental footprint. Indeed, sustainability requires a balanced development of human, social, financial, and environmental growth. Masdar City is one of the world's most enlightened smart city initiatives because it attempts to simultaneously reduce three of the four kinds of capital. Compared to a baseline system, Masdar City achieves the following sustainable development goals: reducing economic growth by 8.33%, decreasing environmental footprint by 74.34% and improving social welfare by 10.46%. Life cycle damage assessment on Masdar City residents examines tech innovation throughout the world and results in a national damage of USD 40.3 million, an environmental damage of USD 38.5 million, and a social damage of USD 12.9 million [2,4,5]. An evaluation based on these results highlights the roles that the UAE can play in a sustainable development strategy.

Environmental issues are a key factor in air pollution controls, which are increasingly affecting both life cycle cost and public health. Life-cycle costing serves as a cost assessment tool to reduce the total cost of air-pollution-control projects. To integrate all the costs of such projects, alternative decision rules can be applied to optimize the main cost group identified for each primary air pollutant. Optimal direct, indirect and intangible costs – associated with life-cycle costing – can help identify the most cost-effective control levels during the different phases of a project’s lifecycle. Complete life-cycle cost analysis can provide decision makers with useful information for making informed decisions.

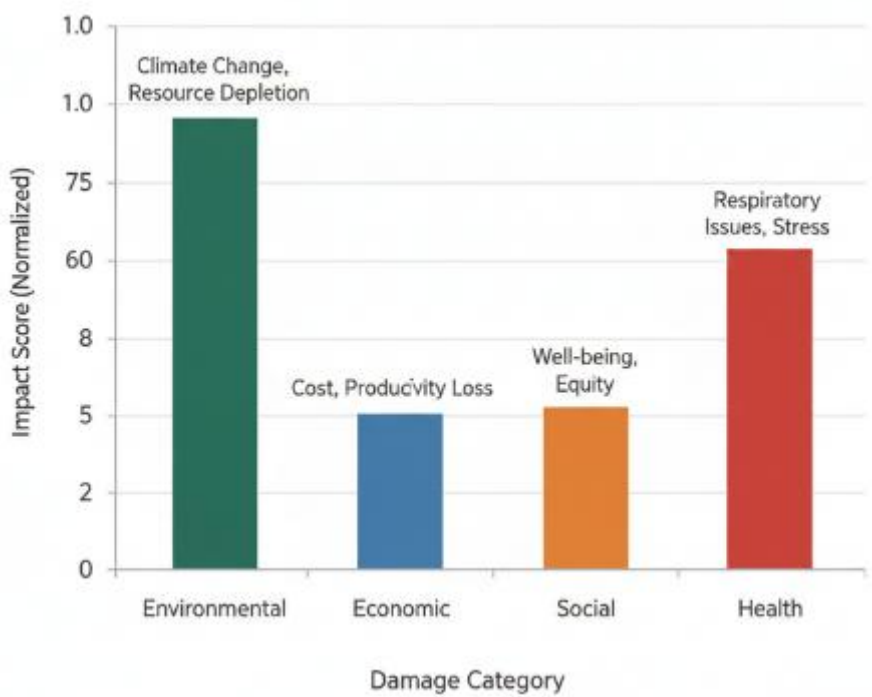


Fig 12 . 2 : Life Cycle Damage Assessment on Masdar City Residents

12.4.2. Resource Efficiency

The technological developments in data centre infrastructures have increased the computational and storage capacity over the years. Cloud data centres work together with the help of the internet and provide services for the whole world. The relatively low cost of maintenance and higher profitability of such hybrid cloud infrastructures make them an attractive and efficient solution for clients. However, in the existing cloud data centers, a large amount of computing resources remain idle, and those virtual machines remain active. An energy-saving mechanism aims to turn off or put the server in a

sleeping mode to reduce energy consumption. Many companies have proposed turning off such idle servers to reduce power consumption. Turning a server on or off excessively can affect startup time and its lifetime. Sunil et al. proposed an algorithm for energy saving in heterogeneous data centres along with virtual machine migration.

Adding energy efficiency in cloud data centres supports a sustainable environment for forthcoming generations. Such research studies the reduction of power consumption of servers in a data centre environment. The power management of the equipment plays a pivotal role in the transformation of existing infrastructures into eco-friendly systems. Constant innovative research in the data centre energy management domain has introduced state-of-the-art and cost-effective algorithms. These solutions support the business model of service providers and provide a better user experience. Tbik et al. conducted a simulation-based analysis of resource management. Their results indicate that the majority of systems use multiple distributed resources for a single process in a cluster environment.

12.5. Cloud Computing and Sustainability

Cloud computing is an abundantly available, easy-to-access, and highly efficient infrastructure that enables access to information and communication technology (ICT) services on demand with resource pooling and rapid scalability [132-135]. It offers services in the form of platforms, storage, or software employing an intelligent infrastructure, providing access to computational resources such as processor power, data storage, and computer memory. Several cloud service models include Infrastructure as a Service (IaaS), such as Amazon EC2 and Rackspace, Platform as a Service (PaaS), like Microsoft Azure and Google App Engine, and Software as a Service (SaaS) exemplified by Google Docs and IBM LotusLive. Cloud services can be deployed via private clouds, public clouds, or hybrid clouds. In smart cities, cloud computing is utilized to access, store, and disseminate data among various applications.

Although cloud computing enables smart cities to contribute significantly toward achieving carbon dioxide targets for energy consumption, it also facilitates the realization of operations that can be serviced directly from the cloud, simplifying energy usage in both operation and design phases [1,3,6]. Energy usage is a critical consideration during all stages of cloud-utilizing technology development, including research and development, design, production, operation, and decommissioning. The emerging field of energy-optimized cloud computing focuses on assessing and optimizing the environmental impacts of cloud services to provide greener services and reduce the carbon footprints of both individuals and corporations. Both cloud users and providers play essential roles in this process: cloud users select cloud services with lower

carbon footprints during operation; cloud providers evaluate new applications and implement carbon footprint reduction techniques during cloud service operation.

12.5.1. Energy Consumption in Cloud Data Centers

Cloud computing enables on-demand resource supply over a network. These cloud-enabled advanced technologies—smart grid, smart home, and smart metering—require large-scale processing, storage, and real-time capacity operating at the edge of the smart technology environment. The cloud platform provides these three functionalities, depending on each type of smart technology and terminal. The cloud platform for processing is integrated with HPC to process the energy transmission and daily analysis. The cloud platform that provides the storage facility for power transactions is integrated into a NoSQL system. The cloud platform that supports the real-time scenario for intrusion detection will be integrated with the design of the stream computing application using Apache Storm. However, the facilities of HPC, NoSQL, and Storm are very resource-intensive and require high energy consumption to meet demand. An eco-friendly cloud platform for smart technologies could be the solution for energy consumption minimization in support of a sustainable environment.

The main element in a cloud environment is the data center. Reducing energy use in cloud data centers can contribute substantially to making the environment more eco-friendly. Research into sustainable design should begin with the energy consumption of the cloud data centers. Interrelated research on other areas of cloud-enabling technology for smart grid, smart home, and smart metering is also essential for developing a sustainable green cloud infrastructure.

12.5.2. Green Cloud Solutions

Smartness applied to complex systems and continuous development of challenges requires a high capacity for creating and responding. An energy-efficient solution should consider methodologies and techniques that minimize the use of natural resources. Building a Green Internet of Things Architecture (G-IoT-A) using the Cloud-Edge-Fog paradigm allows for the design and deployment of smart services during their operation in the environment. Services can be developed using the Green Software Development Life Cycle (G-SDLC), where requirements are redefined multiple times throughout the life cycle to optimize the overall energy consumption of the Green Smart Environment (G-SE) service.

Ultimately, the design and execution of all services should be oriented to the design and implementation of smart Green technologies that optimize resources in the physical

environment. This orientation requires proposing an architecture like Green Cloud–Edge-Fog-IoT (G-CEFI). Additionally, a methodology such as the Green Solution Life Cycle Modeling (G-SLCM) can minimize the consumption of resources needed in the various phases of a smart service. During execution, the Green Smart Environment (G-SE) dynamically manages services, as defined in the Green Program and Control (GPC). These mechanisms not only optimize service consumption but also reduce impact on natural resources and the environment by minimizing the consumption of energy, water, and food and reducing the emission of gases and other pollutants.

12.6. Smart Technologies in Urban Environments

Smart technologies play a significant role in modern urban environments. The cities of Hong Kong and Shenzhen, for example, have embraced smart designs to facilitate daily living and offer exciting activities for residents and tourists. Smart infrastructure supports smart tourism by providing crowd and transport management information. Crowdsourced data offer up-to-date insights, enabling users to formulate traveling plans during large festivals such as the Hong Kong Arts Festival or the Hong Kong International Film Festival. The massive volume of data generated requires storage and processing capabilities offered by recent cloud developments. At the same time, these smart applications consume a great deal of energy. The increasing demand for cloud applications presents a momentous challenge for industry and academia.

With the fast-growing demand for cloud applications, the energy expenditure of cloud data centers has become enormous. Furthermore, the route-through devices consume a huge amount of energy for forwarding the users' data. Cloud data-centers and route-through devices are typically operated continuously, whether or not the energy demand is at a peak or bottom since the expectation of power-on status ensures the real-time response to the users. To reduce the accident risk of no-power servers, they are usually over-requested during design with capacity planning, and the generated over-provisioning is also proven to be a huge energy waste [7-9]. The unnecessary energy consumption of cloud data-centers and route-through devices not only causes energy waste but also further imposes the environmental burden globally.

12.6.1. Smart Grids

Authentication and encryption mechanisms should be developed, with the main concerns being the protection of maintenance, monitoring, and service information traffic.

Energy consumption remains one of the biggest issues of current communication networks. Given the growing number of connected devices and the rising demand for

data traffic, it is necessary to develop new techniques to reduce consumption in the next generation of telecommunication networks. A base station model is proposed in order to evaluate the energy consumption and the energy efficiency of different cell structures and to study the effect of deploying cell switches for current and future telecommunication traffic. The obtained results show that the energy consumption of the network could be reduced by turning off the base stations when the traffic decreases, provided that the corresponding layer cell cannot provide coverage or the number of users that it can serve is limited. Moreover, reducing the size of the cells leads to a significant reduction in energy consumption. A processing resource sharing design model is proposed to allocate bandwidth and consolidate flows. Likewise, it decides which nodes and links need to be active based on the given flow requirements and reduces unnecessary energy consumption. Without resource sharing, the model increases the power consumption by roughly 56%. The municipalities also require special attention when it comes to the national climate and energy plan.

12.6.2. Smart Transportation Systems

Emerging cloud-enabled smart technologies for future sustainable living leverage smart systems in five areas: smart transportation, smart cities, smart grids, smart homes, and smart agriculture. Ground transportation currently uses about 20% of all the energy consumed worldwide and contributes 27% of all greenhouse gases (GHGs) emitted. Only through an innovative and systemic approach can ground transportation achieve sustainability. An innovative cloud-enabled transportation system will act as the backbone for the other smart systems. Moreover, it can provide an important contribution to sustainability by prompting a move from the vehicle-centered system to an integrated and multimodal interurban transportation system where ground transportation is one of the options available to travelers. Current systems are producing toll delays, unsafe travel, and pollution—significant contributors to GHGs, high energy consumption, and fatalities.

Innovations will be incorporated that aim at addressing these aspects by exploiting global information. Malfunctioning vehicles within toll tunnels are the main cause of congestion in one of the busiest locations on the East Coast of the United States. To back up operators in identifying these vehicles as early as possible, a cloud-enabled high-energy Vibration Detection System (VDS) platform is proposed that is able to identify malfunctioning trucks in real time. The system identifies incidents at the VDS station and instantly informs the Central Operations Staff, allowing qualified users to have real-time visibility of traffic conditions. Manually identified incidents at the tunnel and the Port Authority Trans-Hudson (PATH) are injected into the cloud platform to advise operators of conditions at the toll plaza.

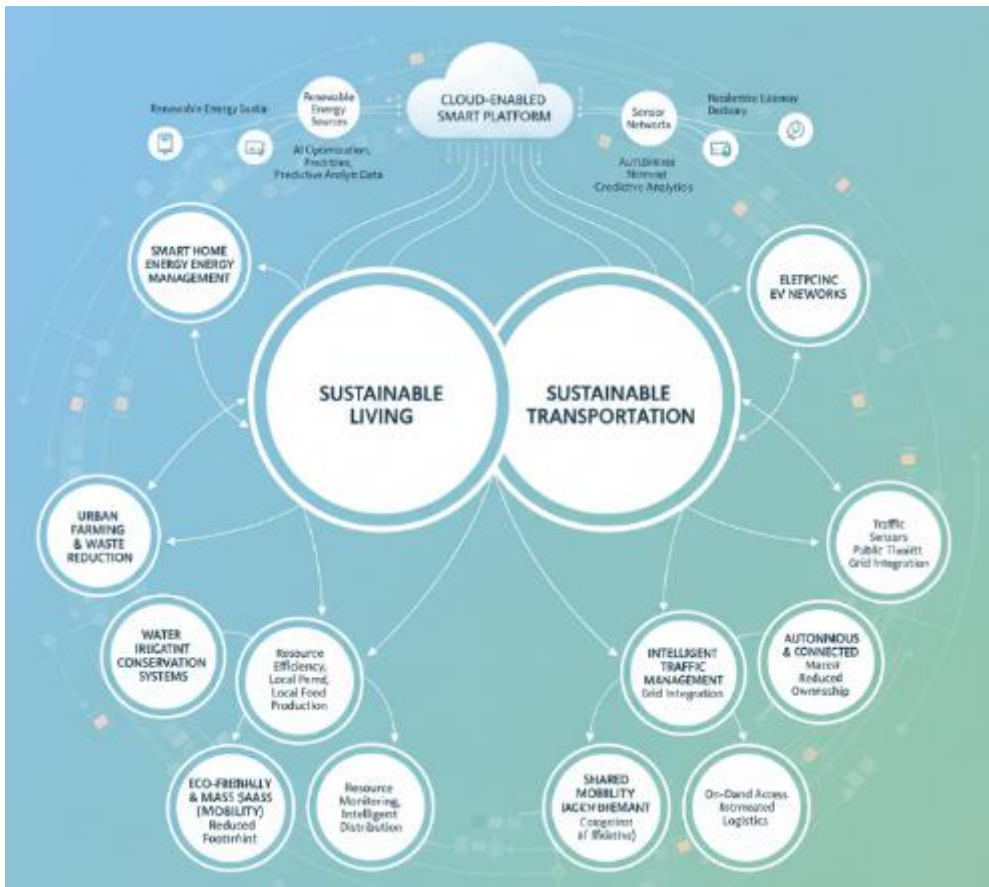


Fig 12.3 : Cloud-Enabled Smart Technologies for Sustainable Living and Transportation

12.7. Energy Management Strategies

The fog layer constitutes an intermediary form of Cloud Computing, dedicated to performing storage and processing operations outside of the central Cloud Computing center. Located closer to the end user, this hierarchical structure resolves problems derived from high latency and facilitates the execution of required actions. Consequently, a large quantity of data-analysis-based decisions can be executed in the proximity of their point of origin.

Cloud Computing represents the concept of managing and delivering electronic resources-online services such as servers, databases, networks, applications, and workstations. Users do not require familiarity with the technology's internal working, instead gaining access only to the resource and ability to manage it as well as the assured level of performance. Despite the achievement of energy reductions within conventional

data center management, the inclusion of other computing services also consumes a considerable amount of energy and releases carbon dioxide. Utilizing Information and Communication Technologies to improve operational efficiency and reduce emissions in other industries is recognized as Smart Energy, which promotes the enhancement of energy-management systems across all industrial sectors. Upon the emergence of Cloud Computing, Smart grids also progressed to smart energy grids by incorporating intelligent control within the communication layer. These communication networks significantly influence the overall energy consumption of the networks. Designing networks that support the energy consumed by these communication technologies is highly desirable. Minimizing power consumption in Cloud Computing not only reduces associated costs but also facilitates additional investment in producing energy by integrating advanced and cleaner networks into the existing power-generation structure. This approach also contributes to the creation of Sustainable Development, shaping the economy by establishing a better infrastructural factor, based on the reduction of energy consumption and emissions.

12.7.1. Demand Response Programs

Demand response programs generate participation among electricity customers by a change in electricity consumption in response to an incentive, such as a price reduction, or an intervention, such as a reservation of dispatchable load, to achieve an economic or operational power system objective (P. Siano, 2014). Demand response enables customers to modify consumption in response to signals from the system operator, without relying on price signals, and it is often triggered through economic incentives for providing reserves that reduce the net cost of electricity services (M. M. V. L. Narayana, 2013). These programs are unusual in that the usual causal direction of electricity information is inverted: the signal originates with the supplier rather than the consumer and is sent out to all consumers simultaneously. North American region demand response programs are divided into ten major programs and include capacity market programs; ancillary service programs; revenue quality price programs such as real-time pricing; tariff-based incentives such as critical peak pricing; and time-of-use pricing.

Demand response providers are responsible for both the management of distributed resources and their response to signals sent by a demand response operator [8-10]. Demand response management generates incentives for the control of power consumption, which, in turn, is capable of creating a reliable electric power delivery system for the end-user. Implementing demand response management in future smart community structures, which depend on advanced metering infrastructures, provides guaranteed power system reliability and quality, grid stability, and meets incentives.

Incentives provide the participation required by electricity customers through a change in consumption or capacity reserve. Electricity consumption can then be effectively reduced when there are supply shortages in the market or there is a risk of grid instability, and new resource capacity can be saved when reserve services are utilized in the demand response program.

12.7.2. Energy Storage Solutions

As societies evolve toward carbon neutrality, energy storage technologies become increasingly crucial for a variety of applications ranging from backpack electricity suppliers for portable and wearable electronics, to microgrids for smart homes, mega projects of wind and photovoltaic power generation, industrial user-side demand response, and natural gas power generation peaking. One particularly attractive energy storage option is electrochemical energy storage, which encompasses batteries and electrochemical capacitors. Among batteries, lithium-ion batteries, known for their high energy density, long cycle life, and environmental friendliness, have been the cornerstone of energy storage solutions in recent decades. However, the increasing scarcity of lithium resources and concerns over safety issues associated with the use of organic electrolytes have detracted from their advantages.

In parallel, supercapacitors, often referred to as ultracapacitors, engage charge storage in electrochemical double layers and thus exhibit cyclic lifetimes that are typically two orders of magnitude longer than lithium-ion batteries, making them ideal for applications demanding a protracted operational period. Their unique properties render them suitable for diverse applications in electric vehicles, pulses of high power current, and portable electronics. Many types of supercapacitors, including aqueous, organic, and ionic liquid systems, have been investigated for their charge storage characteristics. Of these, aqueous supercapacitors stand out for their cost-effectiveness, high ionic conductivity, non-toxicity, and safety. Improving their energy density remains a pivotal challenge. Carbon-based materials have long been preferred for capacitive electrodes owing to their long-term cyclability, excellent reversibility, and relatively high surface area. However, their energy density is limited by the physical nature of charge storage in the electrochemical double layer. To overcome this, pseudocapacitive materials with high redox capacitance have emerged, enabling the Faradaic charge storage mechanism necessary to meet the increasing demand for higher energy density in supercapacitors.

12.8. Future Trends in Sustainable Design

Cloud computing in the context of smart technologies is a rapidly evolving field. In a world that is getting hotter due to the burning of fossil fuels, it is imperative to secure a

sustainable future by designing energy-efficient smart technologies. The continuing evolution of smart technologies using the Internet of Things (IoT) makes the trend of developing more and more smart gadgets inevitable. The operation of these smart gadgets is mainly based on cloud computing. Cognizance of the past and future trends in cloud computing is necessary to find a safer and sustainable future for humanity. Cloud computing is the backbone of any smart technology, and the fact that power is still harnessed from non-renewable sources makes it unsustainable. A technique to design smart technology to make it more energy-friendly is the use of a virtual machine (VM) placement and a VM migration technique with energy optimization.

12.8.1. Innovative Materials

In natural materials, the organization of structures into lamellae that have fibers oriented alternately orthogonally is common. This structuring strategy is frequently transferred to technical materials, as demonstrated by the usage of plywood in wood-based panels or by the lamellar structured lamellar carbon fiber reinforced polymers. Such design enables the targeted creation of mechanical property anisotropy, in particular, the increase of shear strength as well as the reduction of the notch sensitivity.

Biscuits represent an alternative lamination for multi-material design. Their function is the invention of concentrated bonds of high stiffness perpendicular to the lamination, leading to a drastic increase in shear strength. The visualization of transferred stresses inside a vortex béton design retroactive stress visualization system highlights the efficient shear load transfer. Building on this principle, the Biscuits concept enables organized stress dissipation between layers. Dependence on the biscuit geometry (equilateral shape with possible oval deformation) allows for the targeted direction of the maximum of shear forces between the layers. The method thus allows efficient minimization of inner stresses caused by constructive knots in loaded flat structures.

12.8.2. Circular Economy

The circular economy provides a plan for sustainable development that involves resource optimization and reuse. It combines, in one unique model, sustainable development and optimization of the environmental burden. The circular economy implements a sustainable business model based on resource consumption reduction, reuse, and recycling. The focus is on ecodesign, renewable resources, renewable energy, and the waste management cycle. The resources contribute to the sustainable growth of an ecosystem by eliminating the waste generated. Consequently, the antagonistic relationship between resource consumption and environmental concerns gets mitigated.

The environmental impact of resource consumption is limited by decreasing the pollution content in the water and the air, for the sustenance of biodiversity.

Cloud technologies require large amounts of energy, which leads to unsustainable technologies. Wireless sensor network nodes are usually restricted in energy consumption. Combination with cloud services is inevitable in providing a certain service. Ecodesign optimizes the energy consumption at levels of cloud services provision, which involves the wireless sensor network nodes, for long-term use and energy saving. However, it is insufficient by itself. Ecodesign should be extended to energy intelligence also in the wireless sensor network nodes. Both systems have an energy optimization module that manages energy consumption smartly. By managing the energy consumption on the node of the wireless sensor networks and the cloud services, as part of the ecodesign, an intelligent functionality is added to the whole system.



Fig 12 . 4 : Circular Economy, Cloud, and WSN Integration for Sustainable Energy Management

12.9. Conclusion

Smart technologies enable and build upon a smart lifestyle that relies on smart homes, smart communities, smart utilities, and smart infrastructure with security and interoperability. Cloud services that take advantage of big data, artificial intelligence, and data analytics further enhance smart technology services, making operations more efficient and cost-effective. Cloud computing foundations can transform society toward the public good. In the context of infrastructure, smart infrastructure is a tool for protecting the environment through smart-energy monitoring, and smart communities can optimize traffic through cloud-enabled intelligent transport systems.

The inclusion of smart solutions in modern buildings is beneficial for the environment by reducing emissions and energy usage. Incorporating cloud computing further enhances the benefits of smart buildings, enabling city and community users to control and manage their resources efficiently. Although cloud-based smart technologies provide numerous benefits, cloud services and nodes must be optimized to reduce latency and service execution cost, thereby lowering power consumption and minimizing greenhouse-gas emissions. Ultimately, the conservation of human-made resources also benefits the built environment.

12.9.1. Key Takeaways and Future Directions in Sustainable Design

Sustainability is at the top of the agenda of research worldwide. Advancements in the IoT domain provide a support ecosystem to ameliorate the carbon footprint and reduce energy consumption in sectors such as smart farming and smart manufacturing. AI-supported smart services use cloud-based platforms that consume significant energy. At the same time, there is a constant push to incorporate sustainability into real-world applications. This chapter evaluates the cloud-enabled architecture for smart self-powered services and presents a deep cloud workload analysis in terms of energy consumption and carbon footprint. By examining the distribution of execution time, the workload is broken down into short, medium, and long jobs and optimized individually. This analysis identifies the need to incorporate sustainability while continuing the push for the minimization of energy distributed to these cloud-enabled AI-based smart services.

The self-powered service ecosystem presented in the chapter addresses smart farm and manufacturing service sustainability through energy-conscious generation and maximized usage. Self-powered sensors continuously generate data for the cloud-based AI engine in terms of air temperature and humidity for smart farming and vibration data for smart manufacturing services. The ecosystem includes a cloud-enabled sustainable design component that analyses the workload based on energy consumption, global-

warming potential, and execution time. Following the analysis, type-based optimization can be applied, and the workload scheduled accordingly. A multi-objective optimization highlights the variation between sustainable and non-sustainable scheduling policies, thus incorporating sustainability in real-world services.

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