Green by Design: A Methodology for Digital Experience Carbon-Aware Enterprise Architecture (EA)

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ABSTRACT

As a result of this rapid pace of digital enterprise transformation (powered by AI, distributed cloud, and customer-facing digital experience platforms), there is now a serious corporate sustainability paradox: energy use and Scope 3 carbon emissions. There are technical solutions for instance local Green AI, carbon-conscious resource management and automatic emission monitoring, but very fragmented, limited to departmental pockets of IT where there is no macro level business blueprint. That leaves business leaders constantly caught in the dilemma of introducing high level concepts of Environmental, Social and Governance (ESG) into digital systems.

To fill this execution gap, this study suggests a complete and socio-technical framework for Digital Experience Carbon-Aware Enterprise Architecture, called Green by Design. The framework is cantered on Design Science Research (DSR) paradigm and systematic themed analysis of the existing practices in the field of management information systems and combines the concepts of corporate governance, transparency of data, optimization of assets and perpetual life cycle verification into an actionable corporate strategy. The method is based on organizational paradigms (Industry 5.0 philosophy, Social Technological Systems Theory and Value Sensitive Design (VSD)), and on operational tools (Digital Twins and Retrieval-Augmented Generation (RAG) enabled carbon accounting).

The results show that the multi-layered approach to embedding carbon accounting into enterprise architecture can cut data infrastructure carbon footprints by up to 56% and optimise capital expenditure and cloud asset allocation. Moreover, the use of intelligent carbon systems into data validated systems further improves the accuracy of corporate reporting and environmental reporting beyond 90%, mitigating the risk of legal compliance and helping to avoid “greenwashing” of brands. This is a blueprint for the C-suite, Chief Information Officers (CIOs) and sustainability directors to help their companies move forward on the technological side of the business to support sustainability and long-term value for their stakeholders.

Keywords: Corporate Governance, Sustainable Enterprise Architecture, Digital Transformation, Carbon-Aware Management, Green Corporate AI, Industry 5.0, ESG Compliance.

INTRODUCTION

Background of the Study

In all industries worldwide, a digital transformation has started at an accelerated rate, which has changed the value co-creation of organizations and the handling of customer experiences. The deployment of Advanced technologies such as Artificial Intelligence (AI), Cloud Computing, Internet of Things (IoT) and Intelligent Automation is no longer a mere tool for operating, but a strategic capability that can help to build competitive advantage, efficiency and responsiveness. In the existing enterprise architectures, optimization of ‘Digital Experience' (DX) has been a critical element to support business growth and to engage consumers.

However, there's a paradox in the corporate world in all this system being reliant on digital ecosystems. As corporate digital infrastructure has grown exponentially, the energy usage and carbon emissions of enterprises have also increased at the scale. The scale has seen a massive rise in energy consumption and enterprise carbon emissions, due to the growing number of corporate digital infrastructure. The widespread use of hyperscale data centres, decentralized cloud architectures, and resource-intensive AI models puts the pressure on power grids, posing a significant risk for corporations in terms of regulatory, reputational, and financial consequences. For today's modern business executives, the strain of institutions is extremely heavy to marry technology with the environment and with corporate social responsibility.

The strategic tension is just right for the new Industrial Revolution 5.0, where excellence in industry is no longer solely about automation and productivity (Industry 4.0), but is human-centric, resilient, and sustainable, in terms of a new business philosophy. From this social-science perspective, sustainability in the environment is not seen as a law-and-order compliance box to tick. Instead, it has become a forward-looking and integral part of a robust business strategy and governance. Technical solutions like Green AI, carbon-aware workload scheduling and digital twins exist but are being employed as individual technical patches by IT departments. They do not have macro level managerial orchestration. The objective of this study is to investigate this strategic execution gap and provide the architecture community with a proposed solution - Green by Design: A Methodology for Digital Experience Carbon-Aware Enterprise Architecture (EA) that can combine corporate governance, socio-technical architecture and operational lifecycle management (OLM) into an executable business strategy.

Problem Statement

Although there is a great deal of advancement in green cloud computing and automated carbon monitoring, today's corporate applications are still very fragmented, siloed and tech centric. Most organizational interventions focus on small engineering improvements, without considering the impact of those engineering changes at the enterprise level, from the various layers of the enterprise business model. This disconnects leaves company executives still struggling to put high-level business ESG (Environmental, Social and Governance) targets into practice day-to-day using digital tools.

The socio-technical aspect is the disintegration may result in dramatic anomalies of the behaviour and operations such as Jevons Paradox (Rebound effect). Indirectly, the costs of computing can be lowered by the localized technical efficiency improvements, and the more data that is used, as well as the larger scale of computing, can result in greater overall company emissions (Woodruff et al., 2023). This is further complicated by traditional enterprise architecture frameworks that have been designed to maximise the speed, interoperability and money-making potential of the enterprise, and have environmental externalities as an after-thought – not monitored (Fatima, 2023). In the digital ecosystems user-facing to business managers, there is no systematic design and multi-layered methodology to implement carbon accountability.

Moreover, the carbon accounting framework of companies can suffer from poor supply chain transparency and from the inability to track all data, resulting in under-reporting of Scope 3 digital emissions (Blizniukova et al., 2023). Even though there are advanced technologies like Digital Twins and Retrieval-Augmented Generation (RAG) with the potential of measuring the product lifecycle in real time and predicting carbon, these technologies have not yet been adopted in enterprises that have a regular management process (Elghomri & Messaoudi, 2026).

Therefore, there is a great need for integrated socio-technical research-based framework, connecting the executive governance to architectural design principles, algorithmic optimisation and operational reporting. The key is to address this gap to progress and not to hinder institutional net zero targets with the energy of corporate digital innovation.

Research Objectives and Research Questions

This research was done in a systematic manner with the following research objectives (RO) and associated research questions (RQ) from a design science perspective:

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Table 1. Research Objective (RO) and Research Question (RQ)

Research Objective (RO)	Research Question (RQ)
RO1: To identify the strategic and structural enterprise architecture principles required to sustain carbon-aware digital experiences.	RQ1: What socio-technical and architectural principles support the governance of sustainable Digital Experience Enterprise Architecture (DX EA)?
RO2: To evaluate how Green AI strategies can be operationalized to lower corporate carbon footprints.	RQ2: How can Green AI frameworks be leveraged within business processes to reduce enterprise-wide emissions?
RO3: To assess the managerial utility of Digital Twins and RAG-enabled Large Language Models (LLMs) in corporate sustainability governance.	RQ3: How do Digital Twins and intelligent carbon accounting systems enhance enterprise visibility and predictive sustainability management?
RO4: To develop an integrated, multi-layered framework that unifies green governance with operational digital infrastructure.	RQ4: How can strategic corporate governance, system architecture, algorithmic efficiency, and operational lifecycles be integrated into a unified methodology?

Significance of the Study

The study is relevant to the literature of social science and business management studies because it takes the fields of study of Sustainable Enterprise Architecture and Corporate Carbon Governance to a new level. The research integrates the principles of Industry 5.0, Value Sensitive Design (VSD) and socio-technical systems theory to help deepen the understanding of how corporate technologies can be designed around values and environmental care (Umbrello, 2022). It reframes enterprise architecture as an enterprise governance and strategic change management mechanism and not simply an IT function.

From a practical perspective, this study provides a blueprint for a systematic action plan to tackle corporate greenwashing and help C-suite executives and Chief Information Officers (CIOs) and sustainability directors make sense of the evolving world of ESG disclosures. These strategies are also financially viable, as deep reinforcement learning scheduling can achieve carbon footprints reduction in cloud data centres by as much as 56% (Bharathi et al., 2026). Moreover, with the integration of corporate accounting, the effect of RAG may be further enhanced in reporting and disclosure accuracy, which is above 90% (Zhang et al. 2024). These metrics are an unambiguous measure of how much business leaders are really saving their businesses from financial risks, reallocating cloud assets and building brand equity for "green" consumers.

SCOPE AND LIMITATIONS

This study is designed to focus upon corporate digital experience ecosystems, cloud software-as-a-service (SaaS) environment, enterprise AI applications and corporate digital infrastructures. Academically the paper adopts the Design Science Research (DSR) methodology as this is a well-established methodology for creating new and useful solutions to real life business problems and is supported by a systematic detailed analysis of the literature, which is organised around themes.

There are several institutional and operational constraints to be highlighted. The first thing to be noted is that the proposed methodology is conceptual and has not been validated in the empirical and longitudinal sense in the real-life situation of a corporation. Secondly, the ROI of the organizational change and the exact efficiency of such implementation that is Carbon-Aware depends on external hardware infrastructures and area power grid configurations ("Towards Carbon-Aware AI," 2026). Finally, on the change management side, there are no common adoption industrial frameworks across platforms and the integration into current corporate systems may pose challenges (Devadas & Sowmya, 2026). These boundaries help to establish the context as a feasible and practical next step for future empirical trials and company implementation.

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LITERATURE REVIEW

Introduction

This fast pace of sustainable digital transformation has been gaining attention and interest from academia and management in the field of Sustainable Enterprise Architecture (EA). With the rapid speed of sustainable digital transformation, the field of Sustainable Enterprise Architecture (EA) is gaining more interest of the academia and management.

Today in an increasingly digital world, the impact on the environment of the large use of computing power is not only an operational issue but also a real executive's problem as companies increasingly depends on digital assets. The strategic paradox digital leaders are facing in the modern enterprise is the tension between performance and efficiency in digital platforms and achieving the ambitious targets of a corporate net zero strategy (Fair, 2022).

In the literature, various methods are proposed to address digital carbon footprint in an ad hoc fashion, such as automated scheduling, automated machine learning asset monitoring and operation workflows, software energy tracking (Bharathi et al., 2026; Xu et al., 2025; Zhang et al., 2024). In regular corporate setting, however, those tools are typically used alone by various technical groups. Such disjointed measures and projects will not provide enterprise-wide carbon accountability without macro-managerial blueprint. To meet the goals of eco-efficiency in the day-to-day life cycle of a company an inter-functional view of corporate governance, organizational structure and end-to-end operational cycles are needed (Müller et al., 2023; Umbrello, 2022).

This chapter provides the sociotechnical and managerial background of sustainable digital systems, the state of the art on empirical studies and the current execution gaps in management for digital systems that are highlighted and addressed by the proposed Green by Design framework.

Develop the basic concepts and theories

The concept of this research has been built around four perspectives of the organization and the behaviour in terms of Carbon awareness, Architecture, Business and Management. Generally, these lenses offer a considered basis for exploring the interactions between the environment and corporate technological design.

Table 2. Theory and Main Strategic Principle

Theory / Paradigm	Main Strategic Principle	Operational Role in the Green by Design Framework
Industry 5.0 Paradigm	Human-centricity, corporate resilience, and environmental stewardship	Establishes the macro-level corporate vision and strategic foundation
Sociotechnical Systems Theory	Seamless alignment between human behavioural networks and technological structures	Drives the organizational governance, policy design, and change management layers
Value Sensitive Design (VSD)	Active integration of human values and ethics into early-stage engineering designs	Informs design principles for user experiences and digital asset architectures.
Strategic Multi-Objective Optimization Perspective	Systematic balancing of conflicting corporate variables (e.g., speed, expenditure, sustainability)	Guides operational decision-making and resource trade-offs.

Industry 5.0

The Industry 5.0 paradigm is not just a continuation of the Industry 4.0 vision of an automated production process, but also directly places human welfare, systemic resilience and environmental sustainability on the management agenda of any company (Fair, 2022). Industry 5.0 doesn't just call for technology to be integrated with a social and ecological agenda, it also calls for this to be more than just the 'quantitative throughput' and 'short-term profit maximisation. In this, enterprise digital transformation has two directions: firstly, towards the best possible use of market at the level of operations, and secondly, towards sustainable development in the long-term. For this reason, Industry 5.0 is the general guideline for this study, whereupon carbon neutrality is not merely a mere legal compliance requirement, but an essential competitive differentiator and design goal.

Sociotechnical Systems Theory

One of the key features of the sociotechnical systems theory is the close coupling of the organisational human behavioural and physical technical systems. One of the key principles of this theory is that technological improvements alone do not help to optimize an enterprise's performance; it is necessary to have a system of human workflows, institutional values, organizational cultures and operation assets aligned. This framework emphasizes that the implementation of Green computing devices will not lead to achieving the institutional goals without employee behaviours, procurement approaches and administration policies being in sync. This social-science approach focuses on the need to create effective enterprise-wide carbon policies, with accountability being pushed to cross-departmental level and transparency and tracking of green metrics to all levels of management.

Value Sensitive Design (VSD)

Value Sensitive Design (VSD) is a framework to systematically integrate the basic values, moral duties and interests of stakeholders in technology design from the beginning. Ecosystem preservation and a sense of ethical responsibility must be a part of the design and cannot be tacked on at the end of the building as an add-on.Preserving ecosystems and having a sense of ethical responsibility should not be added as a design feature after a system is constructed, as if it were a patch; it should be part of the design as a condition. (Umbrello 2022) VSD urges the corporate leaders to take it as top priority in the whole software development process to proactively care for the environment, publicize it, and take care of the consumers. VSD is leveraged in this study to enable embedding carbon tracking in enterprise structures and UX. This will help to transform digital sustainability from being audited to part of the overall digital experience for the company.

Multi-Objective Optimization Perspective, Sensual (MOOP)

In the realm of sustainable digital systems within the corporate world, there's a consistent balancing act among different corporate metrics: real-time computational performance, cloud expense, carbon reduction needs, and so forth. The Multi-Objective Optimization perspective provides a blueprint to the manager indicating how he/she might want to optimize these different operational requirements together (Taisiq, 2026). Prior research has shown that structured decision frameworks can enable enterprises to drastically reduce digital energy footprints while at the same time ensuring high customer satisfaction and service quality. This view thus serves as the strategic bedrock to assess the resource trade-offs and manage carbon-aware business platforms.

The Sustainable Enterprise Architecture and Carbon-Aware Digital Experiences concepts will be introduced. The concepts of Sustainable Enterprise Architecture and Carbon-Aware Digital Experiences will be developed.

Sustainable Enterprise Architecture (EA) is a new strategic planning tool for the enterprise and is essential for reaching enterprise-level sustainability goals and visions in the day-to-day activities of digital ecosystem workflows. The traditional EA blueprints are focused on optimizing business operations, technical interoperability across platforms and the regular flow of information. However, due to rising tougher standards of environmental, social, and governance (ESG) the definitions of EA have evolved to include environmental and carbon tracking at every organizational level (Müller et al., 2023).

One key development in this regard is the development of Enterprise-wide Emissions Data Architecture (EEDA). The focus of EEDA is on the harmonisation of corporate reporting structures which enable the breaking down of internal information silos and thus close the reporting gap of digital carbon accounts in an organisation across all reporting layers (Müller et al., 2023). EEDA integrates GHG emissions into the business data streams, allowing for corporate decision makers to precisely track environmental impacts and intervene at the highest strategic level with data-informed decisions. Moreover, the adoption of intelligent sustainable systems based on artificial intelligence, has significantly improved the sustainable EA capabilities. For instance, the CarbonWise CX framework demonstrates the possibility of embedding automated decision logic into enterprise infrastructure to help enable a green approach to asset allocation among different business areas. According to the empirical studies, these intelligent elements can help to reduce digital carbon footprints by up to 34.6% in the running of enterprise systems, indicating the possible impact of enterprise architecture on sustainability issues (Beena et al., 2026).

At the same time, enterprise architecture has become so much larger due to the emerging scale, ubiquity, and sophistication of consumer digital experience. High traffic web apps, distributed cloud services and machine learning models are heavily used by modern organizations to maximize their customer value and engagement. Unlike conventional architecture, which puts a strong emphasis on processing speed, system uptime and interface personalisation, the wider environmental impact of these digital platforms has tended to be neglected. To address this discrepancy, the idea of a carbon-aware digital experience proposes to ensure that sustainability requirements become part of the systems design and implementation that are visible to end-users. Carbon-aware systems are designed to continuously learn as the grid data changes in real-time and adjust data weights, scheduling of resources and distribution of assets to minimize any carbon impact to the grid while maintaining user satisfaction. This can assist companies to maintain customer relations and pave the way for Industry 5.0's goals.

Besides that, systems of systems like Digital Twins and standard Asset Administration Shells (AAS) are emerging, which will improve the interoperability of systems and thus the life cyclability of the products in complex corporate environments (Röder et al., 2025). These configurations, together with Internet of Things (IoT) sensors can provide corporate executives with comprehensive visibility and predictive answers to carbon monitoring. At present, academic research is highly technical and fragmented and technological advances made so far. Only a handful of frameworks talk about the synergy between the three aspects in a business strategy – executive enterprise governance, structural enterprise architecture, and customer experience design. Sustainable Enterprise Architecture thus offers a solid base for the Green by Design approach, which integrates enterprise governance and enterprise digital experience operations into one.

Green Corporate AI and Operational Asset Optimization

Green Corporate AI is a crucial field of business information systems research aimed at minimizing the carbon footprint of cutting-edge business technologies, without compromising on their competitive efficiency and performance. More than traditional technical deployments with an ever-increasing level of complexity and computation power at any cost, Green AI prioritizes the long-term efficiency of resources, the allocation of strategic resources and systemic sustainability throughout the technology's life cycle. With the increasing accessibility of data-driven operations and machine learning applications becoming essential parts of the corporate strategy, embracing Green AI has become an important requirement for a sustainable corporate transformation.

Key parts of this are optimisation during the early design of software assets. Past research has validated that optimisation of software code and improvements to data-processing logic can have a substantial reduction of energy use without compromising the quality of corporate output. Zhao et al. (2023) showed that computation workflow optimization and improving processing logic can decrease localized CO_2 emissions by around 27.86% without compromising data accuracy. The findings from these analyses indicate that there is a great deal of potential for improvement in environmental performance, with little investment, and taking proactive measures with sustainable design decisions.

Aside from the software design aspects that start the process, a method that has proven to have a significant impact on the corporate sustainability management is the allocation of the workloads that has carbon awareness. Typical enterprise infrastructure allocation is "carbon-blind" that allocates computing tasks according to the computation cost and speed. Carbon-aware scheduling, on the other hand, dynamically shifts data workloads across networks, according to the availability of renewable energy at that time and/or location. Research studies based on empirical observations of the GREEN Scheduler framework have even shown that the intelligent workload routing can cut digital carbon emissions by up to 41.2% (Xu et al., 2025). This shows the tremendous potential of temporal and spatial optimization strategies for the management of corporate infrastructures.

In addition, machine learning tools have made corporate cloud asset management so much easier. These automated systems constantly re-optimize infrastructure usage and proactively consume no energy resources or waste by constantly scanning the data from the grid, cloud pricing and environmental parameters. For instance, Bharathi et al. (2026) have found that the carbon footprint of data centers could be slashed by as much as 56% when compared with the traditional, carbon-blind data center management. Further, the automated multi-objective design frameworks can optimize the efficiency of software while maintaining good accuracy, with system energy savings of 30-42% (Taisiq, 2026).

Table 3. Management Mechanism and Core Optimization Strategy

Management Mechanism	Core Optimization Strategy	Documented Carbon Reduction	Key Business Case Benefit
Software Refactoring	Optimizing software workflows and code execution patterns	~27.86%	Minimizes processing waste with zero degradation in user performance
Intelligent Resource Routing	Shifting computing tasks to periods of high regional renewable energy supply	Up to 41.2%	Leverages green energy grid variations to lower corporate footprints
Adaptive Orchestration	Automated, data-driven adjustment of global cloud infrastructure	Up to 56.0%	Maximizes server efficiency and lowers cloud expenditures

Yet modern-day corporate deployments are still “siloed” and technology driven. A lot of times, code refactoring, workload management and infrastructure scheduling don't have direct connections to enterprise architectures or corporate governance requirements. This implies district-level efficiency gains can lead to unanticipated outcomes like the rebound effect or Jevons' Paradox, which refers to the fact that emissions from district-level energy efficiency gains can rise. This could also mean that district-level efficiency gains can have unexpected outcomes, such as the rebound effect or Jevons' Paradox, which is the phenomenon of an increase in total district-level emissions from an energy efficiency gain. To mitigate the risk, there needs to be a strong corporate governance framework in place, with Green AI and asset optimization strategies integrated within it.

Moreover, the progress of generative AI has transformed the way businesses can rapidly and accurately measure and communicate their carbon footprints for ESG compliance. The traditional GHGs are tracked in a highly manual and cumbersome manner, and prone to administrative error. To solve these problems, smart language models are being implemented to make emissions tracking as easy as possible and to analyse lifecycle compliance data. When it comes to standalone AI applications, there were reports of data verification issues and inaccuracies in reporting, but the new AI architectures don't suffer from this problem as they integrate the corporate AI system directly with verified environmental data tables and the internal carbon record database.

One of the most visible is the CarbonReveal auditing framework that pulls all the company's operations into a single location, with the official emissions indices, to enable complete automation of complex Scope 3 carbon compliance tracking. These data-validated carbon systems are then validated using empirical tests to guarantee their accuracy, such that financial and environmental disclosure is over 90% accurate, and there is verifiable and audit-ready data for boardrooms and stakeholders (Zhang et al., 2024).

Even with these transformations in how the companies are functioning, the modern solutions remain the same: the “old schoolhouse” solution of having a siloed corporate solution. Without synergy between Agile software management, Digital Twin tracking and carbon counting of the business, they are unable to move forward regarding enterprise goals. The top priority is to have a common research and practice method, namely the integration of the executive ESG governance system, the structure of the company's operations, green software practices, and automated carbon audit. The Green by Design methodology is specifically designed to fill this gap, offering a structured approach to managers to enable a sustainable digital transformation.

RESEARCH METHODOLOGY

Research Design

The approach used in this study is based on Design Science Research (DSR) paradigm to create a conceptual methodology for Digital Experience Carbon-Aware Enterprise Architecture. In information systems research (ISR), the Design Science Research (DSR) approach has gained in popularity for creating innovative artefacts to address complex problems in both organizational and technological contexts (Hevner et al., 2004). DSR is different from approaches based on explanation, which are aimed mainly at the description of phenomena, in so far as it puts emphasis on the development and assessment of artefacts that offer solutions to practical problems in the real world.

The selection of DSR is apt for this study since it is concerned with developing a structured and concrete methodology which introduces sustainability into the enterprise architecture and it is not testing causal relationships or to investigate behavioural patterns. The proposed Green by Design methodology is an artefact to enable the gap between strategy and operational digital systems in the sustainability context.

The study is based on the three-cycle approach of Design Science Research suggested by Hevner et al. (2004) which includes the rigor cycle, design cycle and relevance cycle. The concepts of Industry 5.0, Sociotechnical Theory, Value Sensitive Design (VSD), and Multi-objective Evolutionary Theory (Fair, 2022; Umbrello, 2022) were used as the theoretical foundation for the study. The design cycle is meant to examine and enhance the Green by Design framework, and the relevance cycle covers the proposed methodology to be relevant to the real-world sustainability challenges of the digital ecosystems of today.

Overall, DSR offers a systematic and iterative way to develop a multi-layered methodology that can incorporate governance mechanisms, enterprise architecture, algorithmic optimization and operational lifecycle management, under a single sustainability umbrella.

DSR offers a framework for creating unique IT artefacts which can address complex organisational issues, particularly the gap between the high-level corporate sustainability objectives and low-level software operations.

The selection of data sources and literature selection

Peer reviewed journal articles, conference proceedings and authoritative academic publications were the primary sources from which this research was conceptual study and secondary data were retrieved. The major scientific databases, namely Scopus, IEEE Xplore, Web of Science and ScienceDirect were used to collect literature. The databases chosen were those that have the greatest coverage of information systems research, AI, enterprise architecture, and sustainable computing research.

The literature search focused on publications up to 2026 and included the following keywords: "Green AI", "carbon-aware computing", "Digital Twins", "Sustainable Enterprise Architecture", "Industry 5.0", "Retrieval-Augmented Generation", "carbon accounting". The strategy for searching was designed to find empirical evidence, conceptual frameworks and technological interventions for sustainable digital transformation.

The material has been selected to ensure its relevance and quality (inclusion criteria). The studies chosen should yield measurable outcomes in the field of energy or carbon or a repeatable technical solution and/or theoretical advances in the field of sustainable digital ecosystems. No studies that did not have empirical evidence or were only speculative were included in the review.

The literature collected was then analysed thematically to look for common themes and connections between the governance structures, enterprise architecture, algorithmic optimisation and the operational lifecycle management. It was then possible to build the pieces of knowledge into a coherent body of knowledge that could provide guidance for the sustainable digital transformation.

Framework Development Process

Table 4 Framework Development Process

Stage	Activity	Output
Stage 1	Problem Identification	Fragmentation of current sustainability approaches
Stage 2	Theoretical Synthesis	Industry 5.0, Sociotechnical Theory, VSD, MOET
Stage 3	Architectural Synthesis	Grouping Green AI, EA, Digital Twins, GreenOps
Stage 4	Framework Construction	Green by Design Framework

The process of development of the Green by Design methodology is systematic and included four stages.

The first phase consisted of the problem identification which was found by an intensive review of the current literature. Previous research showed that current sustainable initiatives are limited, and they mostly target isolated technological solutions like Green AI, carbon-aware scheduling, Digital Twins, and automation of carbon accounting (Xu et al., 2025; Bharathi et al., 2026; Zhang et al., 2024). The results emphasised the lack of a common framework that would be able to integrate sustainability into enterprise systems. The second stage was theoretical synthesis. The concepts from Industry 5.0, Sociotechnical Theory, Value Sensitive Design and Multi-objective Evolutionary Theory were combined to build the conceptual underpinnings of the framework (Fair, 2022; Umbrello, 2022; Taisiq et al., 2026). This stage guaranteed that a methodology was developed that included both technological and organizational aspects.

The third phase in this was architectural synthesis. We analysed the existing approaches on Sustainable Enterprise Architecture, Green AI, Digital Twins, GreenOps and intelligent carbon accounting and classified them into related domains (Müller et al., 2023; Aneggi, 2026; Gu et al., 2025). Some similar ideas were combined to reduce any repetition and make ideas more coherent. Lastly, the fourth phase was dedicated to the construction of the framework. The concepts which were identified, were grouped into a multi-layered structure with governance, architecture, algorithmic efficiency and operational lifecycle management. The layers work together to create the Green by Design framework for Digital Experience Carbon-Aware Enterprise Architecture.

Proposed Green by Design Architecture

The proposed Green by Design methodology is composed of four inter-related layers, all of which enable the sustainable digital transformation.

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The first layer, Governance, sets the objectives for organizational sustainability and sets the directions for carbon aware digital ecosystems. This layer is based on principles of Industry 5.0 and Value Sensitive Design, so as to integrate environmental aspects into decision-making processes of organizations (Fair, 2022; Umbrello, 2022).

The second layer, called Architecture, is all about embedding sustainability into enterprise architectures and digital experience ecosystems. Sustainable Enterprise Architecture principles, Enterprise-wide Emissions Data Architecture (EEDA) and interoperable platforms enable information sharing and provide enterprise-wide carbon visibility (Müller et al., 2023).

The third level, Algorithmic Efficiency, focuses on Green AI and optimizing AI algorithms. Optimization strategies like carbon-aware scheduling, Deep Reinforcement Learning and multi-objective optimization methods enhance resource utilization and minimize computational emissions (Xu et al., 2025; Bharathi et al., 2026; Taisiq et al., 2026).

Operational Lifecycle Management – the fourth layer – focuses on sustainability during operation and maintenance of a system. GreenOps practices, Digital Twins and intelligent carbon accounting mechanisms offer continuous monitoring, predictive analytics and automated reporting (Aneggi, 2026; Gu et al., 2025; Zhang et al., 2024).

These layers can interact to convert strategic sustainability objectives into actions and help build environmentally responsible digital ecosystems.

Validity and Limitations

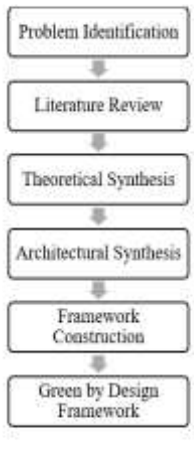
A few steps were taken to improve the validity of the suggested methodology. First, the framework was built on the foundation of theories and supported by evidence obtained through the latest studies. Multiple perspectives lessen the likelihood of bias that would arise from the use of a single theoretical approach.

Second, the thematic analysis allowed for the identification of the commonalities within a range of research fields. This led to a strengthening of the framework and consolidation of the dispersed knowledge into a coherent structure.

However, there are several drawbacks to be noted. The methodology proposed is not empirical and has not been tested through implementation in the field. Thus, its effectiveness in industrial use is still to be evaluated. Furthermore, the effectiveness of sustainability measures can be different depending on the energy and hardware infrastructure, the organizational setting, and the interventions themselves ("Towards Carbon-Aware AI," 2026).

Despite these restrictions, the Green by Design approach offers a structured basis for future empirical studies and helps to advance the research on Sustainable Enterprise Architecture and on carbon-aware computing.

Figure 1: Green by Design Framework Development using the Design Science Research Process



The Results of the Findings and the Development of the Framework

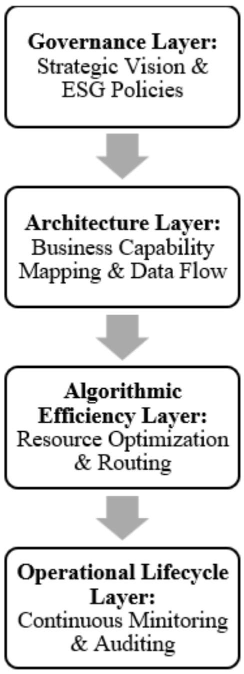
Conducting a literature synthesis of the current literature shows that the current "corporate" approaches to sustainable digital transformation are still very fragmentary and often yield technical solutions that are only applied in isolation. Some technological solutions, like automated scheduling, AI-based monitoring and tracking software and green software tracking, have been proven to be functional, but modern business enterprises tend to have problems integrating these solutions in various departments (Müller et al., 2023; Xu et al., 2025; Zhang et al., 2024). The lack of operation opens a space between chief executive officers and the day-to-day digital operations that makes it difficult to turn high-level corporate Environmental, Social, and Governance (ESG) requirements into action.

To solve this management problem in a systematic way, this study is developing Green by Design Framework for Digital Experience Carbon-Aware Enterprise Architecture. This multi-layered strategic blueprint brings together four inter-dependent layers of the organization: Governance, Architecture, Algorithmic Efficiency and Operational Lifecycle Management. The framework offers corporate leadership an operational process to reduce the carbon footprint of their user-centric digital systems, while also driving the human-centric and sustainable development of Industry 5.0 (Fair, 2022).

The Green by Design Framework provides an overview of the framework

The results of this research highlight that digital transformation can't be realized by technical, isolated intervention of IT professionals alone and thus a truly sustainable digital transformation cannot be achieved this way. On the contrary, long-term carbon accountability demands a full-spectrum sociotechnical management plan that integrates corporate governance policies, data visibility flows, asset-use models and the audit life cycle. The strategic breakdown is made up of 13 layers, as shown in Figure 2.

Figure 2. Strategic Breakdown



Governance Layer

The Governance layer serves as the executive steering structure of the framework, making sure that carbon-reduction goals are firmly established in organizational policy and strategic investments in digital. This layer is not a one-way responsibility of law, but rather a new way of thinking about carbon awareness as a fundamental difference-making tool for business to support the evolution of business activities through the lens of their carbon footprint. As part of Industry 5.0, the focus is not only on technological innovation but

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also on ensuring ecological responsibility and the integration of human values, principles and needs in resilient enterprise systems (Fair, 2022).

This layer is based on the structural approach of the Sociotechnical Systems Theory, which highlights the need for technology to address environmental problems in context. To realize an actual digital efficiency, it is important that the three elements of policy leadership, behavior in-house, and technology platforms are well coordinated. This strategic alignment helps to eliminate IT silos locally and will enable board level ESG commitments to be delivered at the operational level (Fair, 2022).

In addition, Value Sensitive Design (VSD) brings an ethical point of view to early stages of designing digital assets. If stakeholders consider environmental impact to be a priority as part of the initial development of the systems, rather than attempting to rectify environmental systems after they are installed, sustainability becomes part of the organisation's digital ecosystem (Umbrello 2022). This governance model will enable companies to achieve optimum financial results while meeting their corporate social obligations.

Architecture Layer

The Architecture layer helps the Governance layer to create digital capabilities that span the enterprise. The model proposed differs from traditional corporate architectures, where data processing speed and transaction capacity were the only factors considered as key architectural design parameters in the optimization of the architecture.

One of the important features in this level is Enterprise-wide Emissions Data Architecture (EEDA). EEDA is introducing standardised data tracking networks from business units, which are eliminating silos in organisations to create audit-ready carbon visibility (Müller et al., 2023). This data integration helps executives to act on data-informed ESG initiatives. Moreover, the deployment of intelligent agentic software system like the CarbonWise CX framework, can enable enterprises to automate eco-friendly changes over global workflows. The previous research shows that integrating sustainability into the layer of Information Systems (IS) of enterprises can help reduce enterprise carbon footprint by as much as 34.6%, thus providing clear commercial value of sustainable enterprise architecture (SEA) (Beena et al., 2026).

In this layer, Carbon-Aware Digital Experience Architecture is also introduced. Modern interactions with customers place a heavy focus on distributed cloud networks, which is why enterprise services need to be designed to reduce the amount of data sent and compute loads without causing any service disruptions or reducing customer satisfaction. Finally, the quasi-interoperability of digital systems such as Digital Twins and via standardized Asset Administration Shells (AAS) data transparency across platforms (Röder et al., 2025). This structural layer, with support from Internet of Things (IoT) monitoring, provides executives with the transparency of the lifecycle needed to manage carbon emissions.

Algorithmic Efficiency Layer

The Algorithmic Efficiency layer is the operational intelligence component of the framework and is the one that must be optimized for reducing the usage of heavy corporate data workloads and the impact they have on the environment, through green computing strategies. With the rapid proliferation of large-scale computing platforms, controlling the energy inflation of these platforms has become a critical need for sustainable digital development.

Green AI is the main strategy at this level, aimed at maximizing the efficiency of computational assets while sustaining the quality of business output. Previous research shows that by making design improvements in the early stages of software development, the localized digital carbon footprint can be decreased by approximately 27.86% while still maintaining computational accuracy (Zhao et al., 2023).

At the same time, carbon-aware workload routing is a very high-impact approach to corporate cloud asset management. Unlike conventional IT configurations which allocate workloads based on speed and cost, carbon-aware systems automatically shift heavy workloads to times or regions with substantial renewable

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energy resource availability. The carbon reductions by implementing intelligent scheduling models such as the GREEN Scheduler are up to 41.2% (Xu et al., 2025). Likewise, other cloud orchestrators such as GreenCloud can help to lower the energy consumption of servers, thereby cutting carbon footprint of the infrastructure by up to 56% from the conventional carbon-blind operation (Bharathi et al., 2026).

Lastly, the tiered approach deals with the inherent business trade-offs between system performance, corporate spending and net zero goals and targets. With the help of strategic multi-objective configuration metrics, e.g. the model selection approach designed for CAS, executives can detect energy-efficient software configurations. This reduces the operational power consumption by 30% to 42% and computation usage, maintaining the high-end user service value while reducing the consumption (Taisiq et al., 2026).

The Operational Lifecycle Management Layer

The Operational Lifecycle Management layer is a constant monitoring and verification mechanism of the Green by Design framework, ensuring that all corporate digital assets are executed in a systematic way throughout their lifecycle.

The layer's innovative feature is the incorporation of environmental metrics into the traditional agile software deployment and corporate technology pipelines, specifically using GreenOps. GreenOps frameworks combine real-time energy telemetry into the development process to help operational teams identify and solve systemic energy resource inefficiencies before commercialization in the market is released (Aneggi, 2026). For this, virtual Digital Twins help operations managers by simulating the real-time representation of technological assets of the organization, with the purpose of optimizing capacity planning and avoiding operational waste (Gu et al., 2025).

A last important attribute in this layer is intelligent carbon accounting. Conventional GHG measurement is labor-intensive, manual and easy to mess up. Although using generative AI to extract data can automate the process, standalone models often are prone to hallucinating incorrect data. The Green by Design approach overcomes this inherent weakness by utilizing Retrieval-Augmented Generation (RAG) configurations within applications such as CarbonReveal. Corporate generative tools integrated with verified emissions indices and internal data records boost the accuracy of carbon disclosure and reporting beyond 90% (Zhang et al., 2024). This provides the boardroom and external auditing stakeholders with the verified data, which is audit ready, thus avoiding corporate greenwashing.

Managerial and strategic implications discussion

Table 5. Framework Layers and Primary Executive Action

Framework Layer	Primary Executive Action Required	Core Business Benefit Delivered
Governance Layer	Embed carbon-awareness into corporate strategies and financial trade-offs	Stronger brand reputation; active alignment with Industry 5.0 values (Fair, 2022)
Architecture Layer	Standardize EEDA data models across business units to eliminate silos	Full cross-platform data transparency and strategic systems visibility (Müller et al., 2023)
Algorithmic Layer	Deploy intelligent resource routing and Green AI cloud assets	Up to 56% carbon savings; optimized data centre expenditures (Bharathi et al., 2026)
Operational Layer	Institutionalize GreenOps and RAG carbon accounting tools	>90% reporting accuracy; mitigation of legal compliance risks (Zhang et al., 2024)

The Green by Design methodology provides important contributions to both the corporate information systems literature and to the practical ESG governance. It differs from traditional tech-focused efforts that only consider individual technical fixes, by emphasizing the interplay between enterprise governance, enterprise structural architectures, algorithmic asset optimizations and lifecycle tracking workflows. This multidimensional perspective provides businesses with an action-oriented tool to operationalize their wide-ranging corporate sustainability goals into day-to-day activities. In practice, this Plan provides a blueprint for the boardroom for C-suite executives facing mandatory climate disclosure regulations. Thanks to the integration of technological architectures with the concepts of Industry 5.0, the framework maximizes the use of assets, increases the transparency of the data available to companies and promotes eco-friendly business operations. Finally, this closed loop architecture lays the groundwork for future empirical testing and gives a standardized approach methodology for sustainable enterprise architectures.

DISCUSSION

Theoretical Contributions

The Green by Design Digital Experience Carbon-Aware Enterprise Architecture framework presented in this study is an important step in the evolution of knowledge in sustainable digital transformation. Although previous studies have explored individual domains, such as Green AI optimization, Sustainable Enterprise Architecture (EA), Digital Twins, and advanced carbon accounting infrastructures, only a small body of academic research has focused on explicitly mapping out how the various domains, mechanisms, and tools interact organizationally, behaviourally, and managerially (Müller et al. 2023; Xu et al. 2025; Zhang et al. 2024).

The framework that is proposed solves this fragmentation by embedding these dimensions within a single, multi-level strategic framework that aims for a corporate sustainability goal at the enterprise level. This paper builds upon the current Industry 5.0 approach, which is primarily manufacturing-focused, and further explores the theoretical potential of Industry 5.0 in the context of a company's digital experience (DX) and service management systems (Fair, 2022). This approach isn't just about lowering costs and increasing data transaction speed, it's about creating digital architecture that can genuinely promote ecological stewardship and human-centric business performance. Moreover, this approach will implement fundamental principles of Value Sensitive Design (VSD) in Business Information Systems. The methodology shifts the discussion from sustainability as a surface-level compliance ‘patch’ added after a building has been constructed, to sustainability as an integral part of early design considerations (Umbrello, 2022). It transforms digital sustainability from an external audit obligation to an internal and structural asset in today's business structures.

Last, this study pushes the limits of a Sociotechnical Systems Theory, as it shows the complexity of interdependence between underlying digital technological structures and the executive corporate governance policies. IT departments can find themselves dealing with unexpected business anomalies such as the rebound effect, or Jevons' Paradox, as they implement isolated upgrades as reported in the literature (Jevons, 1879; Woodruff et al., 2023), which can lead to increases in data usage and consumption beyond what an IT team might have anticipated. This is a sociotechnical conflict that is addressed by this framework by demonstrating how it is possible to provide multi-layered systems visibility, from corporate governance through structural enterprise architecture, algorithmic asset selection, to continuous and automatic asset deployment monitoring, all of which is important for long-term carbon reduction.

The Practical and Managerial Implications are Discussed

Practically, the Green by Design concept offers a detailed, actionable roadmap for corporate leaders, Chief Information Officers (CIOs), and sustainability managers to turn abstract goals, set by the board on sustainability, into concrete steps that they can implement in their daily operations. This framework can help organizations make the shift from a visionary technical solution to a structured approach to carbon containment and adhere to the growing climate disclosure regulations worldwide while safeguarding their business reputation.

Most importantly, it considers the strategic compromises that are required to keep up with the performance of the calculations in real time, the cost of the cloud resources and the corporate net zero targets. Based on empirical evidence from previous configurations, it can be said that embedding multi-objective optimization architectures, like the CAS-NAS allocation approach, can reduce digital asset power consumption and infrastructure waste by 30%-42% without compromising high quality of customer experience and service availability (Taisiq, 2026). Moreover, financial business case for this methodology is supported by the evidence that intelligent adaptive cloud orchestrators can save up to 56% of the carbon footprint in hyperscale data centres (Bharathi et al., 2026) and hence optimize the allocation of corporate capital and reduce the utility bills of enterprises using cloud computing.

Moreover, this methodology offers an effective benchmark against which to reduce corporate legal liability and avoid the risks of being labeled as "greenwashing" by the market, regulators and customers. Manual GHG tracking techniques are very siloed and susceptible to administrative mistakes and often fail to fully account for (underreport) more complex emissions in Scope 3 digital supply-chains (Blizniukova et al., 2023). The framework can also be implemented with automated Retrieval-Augmented Generation (RAG) systems for auditing pipelines, ensuring a highly secure way for corporate carbon reporting. The direct linkage between generative intelligence models and verified environmental data and corporate records raises data verification and corporate disclosure accuracy beyond 90% (Zhang et al., 2024). This delivers audit-ready, verifiable corporate documents to connect the dots between strategic sustainability goals and digital realities.

CONCLUSION

The study shows that in order to make a digital experience carbon aware, a holistic system perspective needs to be taken rather than a patch perspective in IT. Executive governance, enterprise-wide emissions data frameworks, intelligent routing algorithms for resources and continuous lifecycle monitoring are essential components of a closed loop approach for true environmental stewardship in the digital age. The Green by Design framework provides a systematic approach enabling organisations to work towards sustainable digital transitions and at the same time to actively contribute to the ecological and societal goals of Industry 5.0 (Fair, 2022).

But being a conceptual research paper and a strategic research paper there are some distinct institutional and operational boundaries which must be noted in a clear manner. The first is that the proposed methodology is framework-based and has not yet been validated longitudinally in an in-the-field corporate setting. As a result, the actual ROI (return on investment) and precise carbon mitigation impact of the investment will naturally differ across regional clean energy system configurations, corporate cultures and legacy technological debts (Devadas, “Towards Carbon-Aware AI," 2026). Second, the application of the advanced real-time asset twins in the distributed frameworks can lead to implementation issues in the short term, because currently there is no global cross-platform industrial standardization (Devadas & Sowmya, 2026).

Looking forward, future research directions could involve implementing industrial cases and empirical field tests in various industries, including financial technologies, digital retail, and logistics, to comprehensively assess the framework's applicability, both qualitatively and quantitatively. Furthermore, standardization of business metrics and KPIs should be further developed to continue the convergence of technological architecture paths with international ESG compliance reporting protocols. In conclusion, the Green by Design methodology is a solid and practical approach that digital organizations and companies can use to embark on innovative digital transformations while maintaining their core climate and environmental responsibilities.

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