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AI-Driven Cloud-Native Solar Energy Intelligence Platform for Smart Educational IT Ecosystems

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ABSTRACT: Energy management is becoming increasingly important in the implementation of university IT governance. This need is driven by rising costs, the increasing magnitude of a campus's IT energy footprint, and the requirement posed by Campus 2030. Current energy intelligence platforms are not sufficient for intelligent energy management of campus IT assets because they do not primarily serve educational goals, do not enable IT energy optimization, and do not allow the security and privacy of learners' data to be assured in AI applications.

Solar energy can be considered as a source of clean energy. In addition, cloud-native applications are becoming increasingly important across the IT ecosystem. Within this context, a cloud-native Solar Energy Intelligence Platform (SEIP) for Education is proposed. A SEIP monitors, forecasts, and manages the solar generation of a campus within a whole-of-campus approach. It also allows the intelligent management of the campus IT energy footprint with intelligent demand forecasting capabilities for classrooms and laboratories, while supporting curriculum and pedagogy with specific features. Finally, a curriculum-informing SEIP-Datastore is proposed for seamless integration of all platform features offered by the ecosystem.

KEYWORDS: Solar energy; AI; intelligent solar energy-platform; cloud-native systems; campus operations; educational technology; containerisation; serverless architecture; data governance; privacy; energy-aware IT management; demand forecasting; digital literacy; competencies in sustainable technologies.

I. INTRODUCTION

Hospitals, schools, university campuses, and other public buildings are among the largest consumers of energy. The pressure on their daily energy demands is expected to increase substantially in the years to come. For example, several large-scale sporting events like the Olympic Games or the FIFA World Cup are expected to develop into the most energy intensive activities of modern society. The operation of such large-scale events, and of educational campuses in general, must therefore be established with the focus on providing a sustainable energy network using environmentally friendly technologies. In this context, the continuous development and integration of sustainable technologies in educational facilities is crucial to leading future generations towards more responsible behavior.

Solar energy generation is a prime option for the partial needs of such energy-hungry installations. Modern educational technologies allow the creation of intelligent energy platforms as part of an IT environment. The platform can support smart campus facilities for education and research while assisting efficient energy management. Educational technology is an important enabler of a more sustainable smart digital society. Recent developments in cloud-native technologies allow for the creation of portable and reusable applications in educational technology. These devices can contribute to a more sustainable environment if provided as intelligent services and offered in the public cloud.

The infrastructure-as-code approach, security-by-design features, and data pipeline implementation allow the architecture to be reused in different domains and to supply mission-critical solutions with controlled costs.

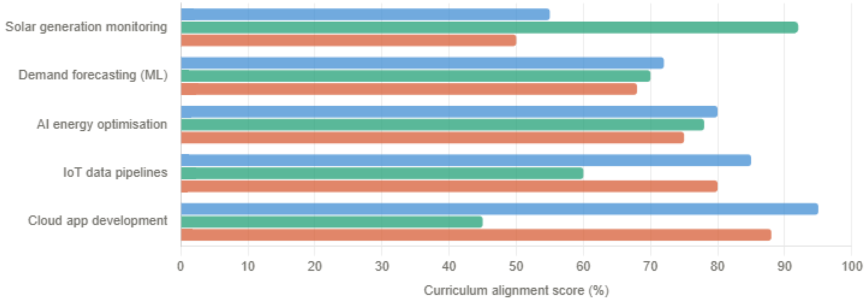


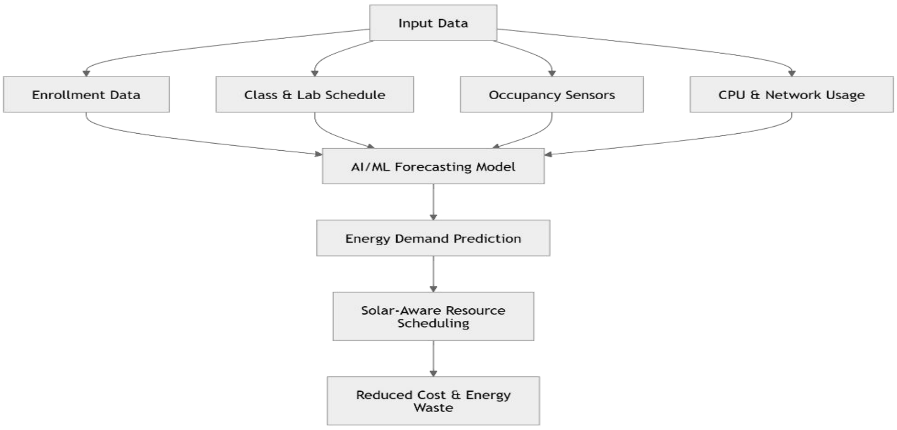
Fig: Curriculum–Platform Alignment quantifies how each SEIP feature maps to the three curriculum frameworks discussed in Section 6.1 — the NZ Digital Technologies curriculum, Education for Sustainability, and the Australian ICT curriculum — showing that solar monitoring leads on sustainability outcomes while cloud app development leads on digital technologies standards.

Technology	**Purpose in SEIP**	**Advantages**
Containerization	Packages applications into portable units	Portability and resource efficiency
Microservices	Modular service-based architecture	Scalability and maintainability
Serverless Computing	Executes event-driven functions	Reduced infrastructure cost
Infrastructure as Code (IaC)	Automates deployment and configuration	Faster and consistent deployments
Ansible	Deployment automation	Simplified orchestration
APIs and Open Standards	Interoperability between systems	Seamless data exchange
Cloud Databases	Centralized data storage	Reliability and scalability

Table. Cloud-Native Technologies Used in the Proposed Architecture

II. BACKGROUND AND RATIONALE

Recent efforts to promote green computing on IT campuses led to the increased use of solar energy. Solar energy harvesting is an intermittent process impacted by seasonal and weather conditions; hence, an intelligent solar energy management platform is needed for an educational IT ecosystem. Such platforms utilize a high-level architecture capable of implementing system-on-module (SoM)-based intelligent structural health and energy-sourcing architectures. Various business models are adopted to satisfy all stakeholders in a solar energy harvesting, distribution, and utilization network. With the emphasis on learning, non-learning, and exams/free faculty laboratory requirements, demand forecasting can be a significant research topic. Providing solar energy in a sustainable way contributes to the attainment of sustainability development goal 4 (SDG 4) for education and SDG 7 for affordable and clean energy…



AI-Based Demand Forecasting Flow

III. SYSTEM ARCHITECTURE

An AI-driven Solar Energy Intelligence Platform comprises layered architecture that integrates data-enabled applications, analytical models, and AI-based decision support within a modular, cloud-native framework. The platform enables digital switches in the energy–education relationship by making educational IT environments aware of their energy demands and allows for real-time monitoring and data-led decision support for their energy use. Supporting the rationale, the architecture is designed for modularity, enabling the effortless addition of new capabilities; cloud-native principles for scalability and resilience; and seamless collaboration among educational systems within an ecosystem. Data exchange for core applications capitalizes on connectivity, portability, and interoperability of formats, APIs, and standards with all key educational ecosystem members.

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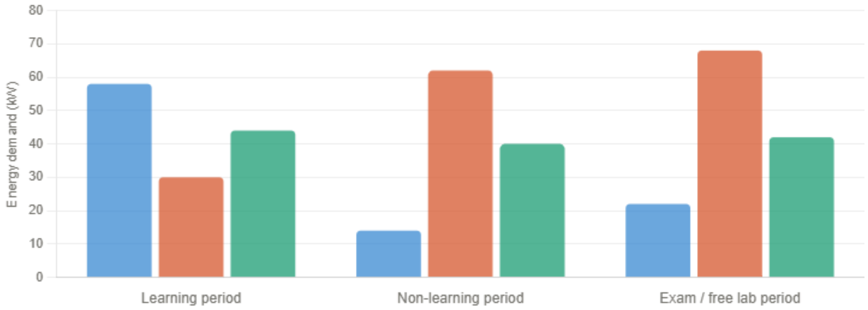


Fig: Demand Forecasting by Facility Type reflects Section 5.1's emphasis on distinct energy profiles for classrooms, computer labs, and data centres across learning, non-learning, and exam/free-lab periods — the three scheduling scenarios the paper identifies as key inputs to ML forecasting models.

AI Application	Function	Expected Outcome
Solar Energy Prediction	Forecasts solar power generation	Improved energy planning
Demand Forecasting	Predicts classroom and lab energy demand	Reduced energy waste
Fault Detection	Detects anomalies in photovoltaic systems	Improved system reliability
Occupancy Analytics	Monitors room utilization patterns	Optimized resource allocation
Smart Scheduling	Aligns IT workloads with energy availability	Energy-aware operations
Predictive Maintenance	Identifies maintenance requirements	Reduced downtime

Table. AI Applications in the Proposed Energy Platform

3.1. Cloud-NativeInfrastructure

Containerized software components (containers) execute resources in cloud-native production and are spun up automatically in response to the incoming requests for resources and events (serverless functions). Cloud-native architectures use standardized building blocks that can be reused across multiple applications running in multiple clouds. The natural evolution of cloud-native architectures leads to a converged IP network that transports data, storage, and compute (data pipes) and runs the elastic and scalable intelligent engines that use AI/ML to optimize the dynamic and static features of the applied AI/ML algorithms while delivering insights to Human-in-the-loop solutions built to be universally usable.

Mathematical Formulation:

1. Solar Energy Generation

Photovoltaic (PV) Power Output:

$$P_{PV} = \eta \cdot A \cdot G \cdot (1 - \beta_T (T_{cell} - T_{ref}))$$

Where:

- P_{PV}= PV power output (W)
- η= panel efficiency
- A= panel area (m²)
- G= solar irradiance (W/m²)
- β_T= temperature coefficient
- T_{cell}, T_{ref}= cell and reference temperature (°C)

Cell Temperature:

$$T_{cell} = T_{amb} + \frac{NOCT - 20}{800} \cdot G$$

Where NOCT = Nominal Operating Cell Temperature.

2. Demand Forecasting (Classrooms & Labs)

Time Series ARIMA Forecasting:

$$\hat{E}(t) = \sum_{i=1}^{p} \phi_i \, E(t-i) - \sum_{j=1}^{q} \theta_j \, \varepsilon(t-j) + \varepsilon(t)$$

Where $\phi_i$are autoregressive coefficients, $\theta_j$are moving average coefficients, and $\varepsilon(t)$is white noise.

Machine Learning (LSTM) Energy Prediction:

$$h_t = \sigma(W_h \cdot [h_{t-1}, x_t] + b_h)$$
$$\hat{E}_t = W_o \cdot h_t + b_o$$

Demand Forecast Error (RMSE):

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{E}_i - E_i)^2}$$

3. Energy-Aware IT Management

IT Energy Consumption:

$$E_{IT} = \sum_{k=1}^{K} P_k \cdot t_k + E_{idle}$$

Where P_k= active power of device k, t_k= usage time, E_{idle}= idle energy.

Power Usage Effectiveness (PUE) for Data Centres:

$$PUE = \frac{E_{total}}{E_{IT}}$$

A PUE of 1.0 is ideal (no overhead energy wasted).

Energy Efficiency Ratio:

$$EER = \frac{E_{solar}}{E_{IT}} \times 100\%$$

4. Cloud-Native Scheduling Optimization

Energy-Aware Task Scheduling (Minimization):

$$\min \sum_{i=1}^{N} \sum_{j=1}^{M} x_{ij} \cdot E_{ij}$$

Subject to:

$$\sum_{j=1}^{M} x_{ij} = 1, \forall i (\text{each task assigned once})$$

$$\sum_{i=1}^{N} x_{ij} \cdot P_{ij} \leq C_j, \forall j (\text{capacity constraint})$$

Solar-Aware Scheduling Benefit:

$$\Delta C = \sum_{t=1}^{T} [P_{grid}(t) - P_{solar}(t)] \cdot \lambda(t)$$

Where $\lambda(t)$= electricity tariff at time t.

5. Data Governance and Privacy (Anonymization)

k-Anonymity Condition:

$$| S_q | \geq k, \forall q$$

Each quasi-identifier group $S_q$must have at least $k$records.

Privacy Risk Score:

$$R = \frac{1}{k_{min}} \cdot w_{sensitivity}$$

Where $k_{min}$is the minimum group size and $w_{sensitivity}$is a data sensitivity weight.

Differential Privacy (Laplace Mechanism):

$$\tilde{f}(x) = f(x) + \text{Lap}\left(\frac{\Delta f}{\epsilon}\right)$$

Where $\Delta f$is the sensitivity of function $f$and $\epsilon$is the privacy budget.

6. Microservices & Containerization Scalability

Auto-Scaling Rule:

$$N_{containers} = \left\lceil \frac{\lambda_{req}}{\mu_{container}} \right\rceil$$

Where λ_{req}= request arrival rate and $\mu_{container}$= container service rate.

Response Time (Little's Law):

$$W = \frac{L}{\lambda}$$

Where L= average number of requests in system, λ= arrival rate, W= average waiting time.

7. Solar Energy Net Balance

Campus Energy Net Balance:

$$E_{net}(t) = E_{solar}(t) - E_{demand}(t)$$

- If $E_{net}(t) > 0$: surplus → feed to grid or battery storage
- If $E_{net}(t) < 0$: deficit → draw from grid

Battery State of Charge (SoC):

$$SoC(t+1) = SoC(t) + \eta_{charge} \cdot P_{charge}(t) \cdot \Delta t - \frac{P_{discharge}(t) \cdot \Delta t}{\eta_{discharge}}$$

8. Interoperability & Learning Analytics

xAPI/Caliper Learning Engagement Score:

$$E_{score} = \sum_{a \in A} w_a \cdot f(a)$$

Where w_a= weight of activity type $a$and $f(a)$= frequency of the activity.

Data Quality Index (DQI):

$$DQI = \frac{1}{5} \sum_{d \in D} [\alpha_c \cdot C_c + \alpha_a \cdot C_a + \alpha_t \cdot C_t + \alpha_r \cdot C_r + \alpha_u \cdot C_u]$$

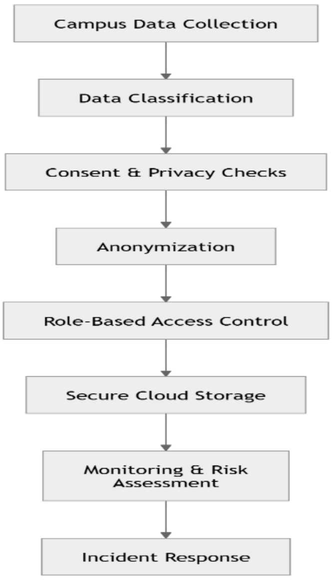
Covering: Completeness (C_c), Accuracy (C_a), Timeliness (C_t), Relevance (C_r), Uniqueness (C_u).

VI. DATA GOVERNANCE AND SECURITY

Data governance clarifies what data are essential for providing services and meeting legal, compliance, and risk requirements. It defines responsibilities, accountabilities, and business ownership of data policies, such as establishing who can access data and how—to meet the legal rules for design and sharing. It also clarifies the processes that assess the data quality, context, and certified origin of the data, the categorization of the data, the rules for data access, and the process for reacting to unexpected events. Secure data management is achieved through privacy and protection settings, which specify the processes that guarantee that user consent is collected as needed to retail, process, and share the data; that data access is restricted to only authorized parties; and that data are anonymized where applicable and protected from security breaches. The impact of breaches on the organization is also evaluated, and the responsibilities and actions to minimize that impact are defined.

Risk is an integral part of a good cloud management strategy. An organization can identify a set of information assets and the risks to those assets, determining the most critical areas that require action. Risk management begins by determining the assets that need to be protected, including intellectual property, customer records, confidential information, and personally identifiable data. For data to be usable, they must be trustworthy.

Energy is a significant operating expense for educational institutions, and campus information technology (IT) systems consume a large share of demand in the course of a year. Academic buildings are typically used during limited time windows in a semester and are often unoccupied. A cloud-native solar energy intelligence platform processes data related to campus IT energy consumption and the generation of solar energy to actively monitor and optimise operations. These data-driven capabilities are used to forecast future energy demand for classrooms and laboratories that contain more power-hungry IT devices. Resident data centres consist of clusters of servers and storage devices with programmable power profiles, enabling the supporting infrastructure to dynamically adapt capacity to the demands placed upon them. Control mechanisms have been redeveloped to consider available solar-generated energy during scheduling operations.



Data Governance and Security Flow

V. ENERGY-AWARE IT MANAGEMENT IN EDUCATION

A cloud-native solar energy intelligence platform supports energy-aware management of educational IT services. Information on energy consumption and generation is integrated into the respective management systems to inform operational decisions and provide key performance indicators for the governance of energy use.

Integration points with the constituent Campus Management System, Remote Lab Management System, and Educational Virtual Machine facility provide dashboards displaying demand and consumption patterns as well as key performance indicators. Energy-aware IT management encourages all stakeholders to consider energy implications in their decision-making processes.

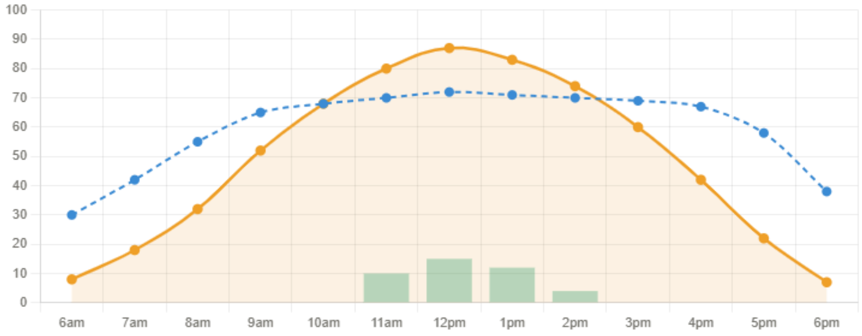
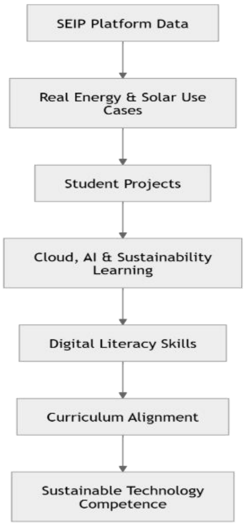


Fig: Solar Generation vs IT Demand (daily profile) illustrates the core challenge the paper addresses: solar output is intermittent and peaks midday, while campus IT demand is comparatively steady. The teal bars show the surplus solar window that intelligent scheduling can exploit.

VI. EDUCATIONAL OUTCOMES AND PEDAGOGY

Aligning the platform's capabilities with specific learning outcomes substantiates the expectation of improving student engagement and competence in digitally-focused curriculum areas, particularly in information management and robust, secure cloud solutions. Facilitating hands-on learning with AI-embedded, containerized, serverless applications that utilize and generate real usage data empowers students to enhance their knowledge and appreciation of sustainable energy solutions. Increased accessibility to development resources encourages a wider demographic of students to gain digitization exposure.

Information on IT energy use supports action-based proposals regarding sustainability enhancement, enabling students to influence real-world operations and implement digital, cloud-based solutions within classroom- or lab-defined constraints. Anonymized data portability increases secondary-level accessibility, establishing numerous reuse possibilities within teaching and research environments. Scenarios for AI-enhanced energy consumption predictions in classrooms and labs that satisfy the required accuracy management process provide additional opportunities for projects that address local educational requirements.



Educational Outcome Flow

6.1. Curriculum Alignment with Sustainable Technologies

Proposed mappings between platform features and learning standards of the New Zealand Curriculum serve as a starting point for developing learning activities, assessments, and project-based work contributing to student engagement and empowerment. Such mappings are relevant not only for New Zealand but for educational institutions in other regions for whom similar sustainability and energy-awareness competencies have become part of their curriculum.

Many relevant standards within aspects of the Technology and Learning Areas of the New Zealand Curriculum are likely to be developed or assessed through one-off projects involving short-term network monitoring, either for research purposes or simply to satisfy curiosity. Other Education for Sustainability learning intentions focused on sustainable technologies could also be achieved via such projects. However, one-off projects are not the only way to enrich a New Zealand Curriculum experience with relevant student engagement and empowerment possibilities. Mappings are proposed below for the integration of three additional platform features into the Digital Technologies and Technology Learning Areas, although these are not the only possibilities for curriculum connections. The alignment of curriculum standards, learning activities, assessments, and project-based digital technologies work enriched by a school extra-territorial solar energy and weather monitoring platform, with core objectives of Education for Sustainability.

Governance Area	Key Features	Purpose
Data Ownership	Defined accountability and responsibilities	Ensures proper governance
Access Control	Role-Based Access Control (RBAC)	Restricts unauthorized access
Data Privacy	Data anonymization and consent management	Protects sensitive information
Risk Management	Asset identification and risk assessment	Minimizes vulnerabilities
Compliance	Adherence to institutional and legal regulations	Ensures regulatory compliance
Data Quality	Validation of completeness and accuracy	Maintains trustworthy data

Governance Area	Key Features	Purpose
Incident Response	Breach detection and recovery procedures	Enhances resilience

Table. Data Governance and Security Features

VII. INTEROPERABILITY AND STANDARDS

Much progress has already been made toward integrating smart IT management at the campus scale (Schlömer et al., 2022; Shui et al.). Nevertheless, a fully instrumented campus with energy-aware IT management features remains elusive. In particular, the integration of educational technology systems—such as learning management, student information, and enterprise resource planning systems—and supportive demand forecasting models may facilitate a more holistic campus energy management paradigm. The following sections address this challenge.

The primary energy-consuming services in educational IT—namely, classrooms and laboratories—exhibit cyclical, predictable load profiles based on enrollment and scheduling. Incorporating these elements allows energy-aware IT management to schedule energy-intensive tasks proactively, strengthen the business case for demand-side response interventions, and achieve more robust forecasting. Models for demand forecasting in classrooms and laboratories utilize enrollment and scheduling information as inputs. A mixed-method approach combining statistical techniques and machine learning methods supports model development and validation. The models have been applied to various scenario analyses and the findings have been shared with IT service providers for further refinement and integration.

Variable	Description	Impact on Forecasting
Enrollment Data	Number of registered students	Predicts classroom utilization
Timetabling/Scheduling	Academic schedules and room allocations	Estimates occupancy patterns
Actual Occupancy	Real-time classroom usage	Improves forecasting accuracy
CPU Usage	IT system workload monitoring	Supports server energy prediction
Network Usage	Campus network activity	Estimates IT energy demand
Weather Conditions	Solar irradiance and climate conditions	Predicts solar energy availability
Seasonal Trends	Semester and vacation periods	Identifies cyclical demand patterns

Table. Demand Forecasting Variables for Campus Energy Management

VIII. CONCLUSION

The research investigates AI-driven cloud-native solar energy intelligence platforms for smart educational IT ecosystems, with a focus on system capabilities, governance, curriculum alignment, evaluations, and outcomes. Solar energy use on campus, realized using an AI-driven cloud-native solar energy intelligence platform, is becoming increasingly important for sustainable campus IT operations; the demand for an integrated educational solar energy intelligence system is now clearly visible.

Intelligent energy platforms provide an avenue to accelerate and achieve the desired capabilities. Further analysis of cloud-native architecture reveals that a cloud-native solar energy intelligence platform enhances the sustainability and resilience of the entire educational IT ecosystem while integrating closely with the rapidly developing microservices-based educational big data capability. The mathematical optimization and machine learning aspects of energy-aware management of IT energy use in education are key areas for research and development, while demand forecasting for classrooms and laboratories is systematically tackled using enrollment, scheduling, and occupancy data as major inputs. Integrating predictive capacity into the energy-aware management capability maximizes potential impact. Together with privacy and security considerations, these aspects form the immediate program of work.

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