

 Research Article



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Proxy-Based Thermoacoustic and Energy-System Perspectives on Solar Drying Technologies: Integrating Cloud GPU Evaluation Frameworks with Advanced Thermal Storage and Control Paradigms

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Arman Kovalenko

Department of Mechanical and Energy Engineering, University of Tartu, Estonia

ABSTRACT

The accelerating convergence of digital infrastructure and energy-intensive physical systems has generated an unprecedented need for unified evaluation frameworks capable of interpreting thermal, acoustic, and energetic performance across domains that were historically treated as separate. High-performance cloud graphics processing units used for artificial intelligence training and solar-driven food drying systems represent two extremes of this convergence: the former embodies dense computational heat generation under controlled environments, while the latter exemplifies distributed, environmentally coupled thermal processes aimed at moisture removal and food preservation. Recent proxy-based methodologies for cloud GPUs have demonstrated how indirect indicators such as thermal gradients, acoustic signatures, and airflow resistance can be leveraged to infer system efficiency and degradation without intrusive instrumentation, as articulated by Lulla, Chandra, and Sirigiri in their 2025 study on thermoacoustic proxy evaluation of cloud GPUs (Lulla et al., 2025). Parallel advances in solar drying technologies have emphasized thermal storage, phase change materials, intelligent control, and structural optimization as key levers for stabilizing temperature and reducing energy losses, as reflected across a wide body of contemporary literature (Pankaew et al., 2020; Rulazi et al., 2023; Yazici and Kose, 2024).

This article advances an original interdisciplinary argument: that proxy-based thermoacoustic evaluation frameworks developed for cloud GPUs can be theoretically and methodologically mapped onto solar drying systems to create a unified paradigm for evaluating, optimizing, and controlling thermal processes in renewable-energy-driven agro-industrial equipment. By situating solar dryers within a broader theoretical ecology of energy dissipation, interface engineering, and feedback control, the study reframes agricultural drying as a cyber-physical system whose performance can be inferred through non-invasive, proxy-driven

analytics analogous to those applied in high-density computing. Drawing on polymer composite and interface science to explain material-level heat transfer and durability, as well as on thermoeconomic and control-theoretic literature to interpret system-level performance, the article constructs a comprehensive framework for understanding how heat, moisture, sound, and structure co-evolve in drying environments.

Methodologically, the research adopts a comparative theoretical design, synthesizing empirical findings from large-scale greenhouse dryers, hybrid mixed-mode systems, parabolic trough dryers, and phase change material-integrated units with the proxy-based GPU evaluation paradigm introduced by Lulla et al. (2025). Through extensive analytical triangulation, the study demonstrates that temperature stability, airflow uniformity, and acoustic emissions in solar dryers function as reliable proxies for moisture diffusion, wall heat losses, and material fatigue, much as fan noise and thermal gradients do for cloud GPUs. The results show that systems incorporating phase change materials, intelligent control algorithms, and optimized wall designs exhibit proxy signatures indicative of lower entropy production and higher exergy efficiency, consistent with thermoeconomic models reported by Nikpey et al. (2024) and Yazici and Kose (2024).

The discussion situates these findings within broader debates on sustainable energy systems, digital agriculture, and material interfaces, arguing that proxy-based evaluation not only reduces measurement costs but also enables adaptive control strategies that can be embedded into future solar dryers. By extending the logic of Lulla et al. (2025) beyond the data center and into the agricultural field, the article proposes a novel epistemology of thermal performance grounded in indirect observation, material science, and systems engineering. This approach has far-reaching implications for the design of resilient, low-carbon food processing technologies in a warming and digitizing world.

KEYWORDS

Solar drying systems; Phase change materials; Thermoacoustic proxies; Cloud GPU thermal evaluation; Energy efficiency; Intelligent control; Sustainable food processing

INTRODUCTION

The global transition toward low-carbon energy systems has intensified scholarly and technological interest in how heat is generated, stored, transferred, and dissipated across both digital and physical infrastructures. In high-performance computing environments, particularly cloud-based graphics processing units used for artificial intelligence training, heat is a by-product of intense electronic activity that must be managed with extreme precision to maintain computational

integrity and economic viability. In contrast, in agricultural and food processing contexts, heat is not merely a by-product but a deliberately harnessed resource, especially in solar drying systems designed to remove moisture from crops using renewable energy. Despite these apparent differences, both domains are governed by the same fundamental thermodynamic principles of energy flow, entropy production, and material-mediated heat exchange, a fact increasingly recognized in recent interdisciplinary research (Lulla et al., 2025; Yazici and Kose, 2024).

The emergence of proxy-based evaluation methods in cloud computing has marked a significant epistemological shift in how complex thermal systems are studied. Rather than relying solely on direct temperature sensors embedded at numerous points within a device, researchers have begun to infer thermal performance from indirect signals such as acoustic emissions, airflow patterns, and power draw fluctuations. Lulla et al. (2025) demonstrated that these proxies, when properly calibrated, can provide highly reliable insights into the thermal health and efficiency of cloud GPUs under AI training workloads. This methodological innovation was driven by the recognition that dense computational hardware is both difficult to instrument and highly sensitive to perturbations, making non-invasive proxy measurements not only convenient but often more accurate. The broader implication of this work is that any system characterized by forced convection, heat generation or absorption, and structural interfaces might be amenable to similar proxy-based evaluation.

Solar drying systems, which have evolved from simple open-air racks to sophisticated greenhouse-like enclosures with phase change materials and intelligent controls, present precisely such a case. Modern solar dryers integrate collectors, drying chambers, thermal storage, and airflow management into a coupled system whose performance depends on the stability of internal temperatures, the uniformity of air distribution, and the minimization of heat losses through walls and leaks (Pankaew et al., 2020; Rulazi et al., 2023). Traditional evaluation of these systems has relied heavily on direct measurements of temperature, humidity, and moisture content, often requiring extensive instrumentation that increases cost and

complexity. Yet, as in cloud data centers, solar dryers generate a rich array of indirect signals, including fan noise, structural vibrations, and airflow resistance, which have rarely been exploited as systematic indicators of performance, a gap that becomes evident when one compares the methodological sophistication of GPU evaluation to that of agricultural drying research (Lulla et al., 2025; Gilago et al., 2023).

Historically, the development of solar drying technology has been driven by practical concerns of food preservation, energy access, and rural livelihoods. Early designs emphasized simplicity and low cost, often at the expense of efficiency and product quality. Over time, however, researchers introduced increasingly complex features such as indirect heating, forced convection, and thermal storage to address the limitations of open sun drying (Bhardwaj et al., 2020; Rehman et al., 2023). Phase change materials, in particular, have been widely adopted to buffer temperature fluctuations and extend drying hours beyond daylight, creating a more stable thermal environment for sensitive products like chili, ginger, and medicinal herbs (Panchal et al., 2023; Malik and Kumar, 2025). At the same time, advances in control algorithms, including fuzzy logic and artificial intelligence, have enabled more precise regulation of airflow and temperature, further improving energy efficiency and product quality (Nafisah et al., 2024; Nramat et al., 2024).

Despite these advances, a persistent literature gap remains in the holistic, systems-level evaluation of solar dryers. Most studies focus on specific performance metrics such as drying time, energy consumption, or moisture ratio, often treating the dryer as a black box whose internal dynamics are



only partially understood (Rana et al., 2024; Joel et al., 2024). In contrast, the proxy-based approach articulated by Lulla et al. (2025) invites researchers to conceptualize thermal systems as networks of interacting components whose behavior can be inferred from a limited set of carefully chosen signals. This perspective aligns closely with the growing field of cyber-physical systems, which views physical processes as inherently intertwined with information flows and control mechanisms, an idea increasingly applied to smart agriculture and renewable energy systems (Yazici and Kose, 2024; Nikpey et al., 2024).

The theoretical foundation for such an integrative approach can be found not only in thermodynamics and control theory but also in materials science, particularly in the study of polymer composites and interfaces. Solar dryers, like cloud GPUs, rely on complex assemblies of materials whose thermal and mechanical properties determine overall system performance. The literature on particulate-filled polymers, interfacial adhesion, and thermal stability provides crucial insights into how heat flows through composite walls, insulation layers, and structural supports, affecting both energy losses and long-term durability (Pukanszky, 1999; Wu, 1982; Ishida, 1988). These material-level phenomena, though often overlooked in agricultural engineering, are directly analogous to the thermal interface challenges faced in electronic packaging and data center cooling, underscoring the relevance of cross-domain theoretical transfer (Rothon, 1999; Qin et al., 2004).

Within this context, the present study poses a central research problem: how can proxy-based thermoacoustic evaluation frameworks developed

for cloud GPUs be adapted and applied to the design, monitoring, and optimization of solar drying systems? Addressing this question requires not only a synthesis of diverse empirical findings but also a rethinking of what counts as meaningful data in thermal system analysis. If fan noise and temperature gradients can reveal the health of a GPU cluster, then airflow sounds, wall vibrations, and thermal lag in a solar dryer might similarly reveal its efficiency, heat losses, and moisture transport dynamics (Lulla et al., 2025; Akuwueke et al., 2025).

The literature gap is thus twofold. First, there is a lack of methodological cross-fertilization between the highly instrumented world of cloud computing and the often resource-constrained field of solar drying. Second, there is an underdeveloped theoretical understanding of how indirect, proxy-based signals relate to the fundamental processes of heat and mass transfer in agro-industrial systems. By integrating insights from thermoeconomics, materials science, and control engineering with the proxy paradigm of Lulla et al. (2025), this article aims to fill that gap and propose a coherent framework for future research and development.

In doing so, the study also responds to broader societal and environmental imperatives. As climate change intensifies and food systems face increasing pressure to reduce waste and emissions, efficient, resilient, and intelligent drying technologies will become ever more critical. Solar dryers equipped with phase change materials and smart controls already represent a step in this direction, but their full potential will only be realized when they are embedded within a comprehensive monitoring and evaluation architecture that enables continuous

improvement, a vision strongly supported by recent thermoeconomic and energy system analyses (Nikpey et al., 2024; Steinegger et al., 2025). The proxy-based approach offers precisely such an architecture, making it possible to detect inefficiencies, predict failures, and optimize performance without prohibitive costs, thereby aligning agricultural technology with the digital transformation of energy systems (Lulla et al., 2025; Yazici and Kose, 2024).

Through this extensive theoretical and analytical exploration, the article sets the stage for a methodological innovation that transcends disciplinary boundaries, positioning solar drying not merely as a rural technology but as a sophisticated thermal system whose behavior can be decoded through the same proxy signals that govern the world of cloud computing.

METHODOLOGY

The methodological architecture of this study is grounded in a comparative, theory-driven synthesis that treats proxy-based thermal and acoustic evaluation as a transferable epistemic framework across technological domains. Rather than conducting a single-site experiment or a narrowly defined numerical simulation, the research adopts a structured analytical design that integrates empirical findings from diverse solar drying systems with the proxy methodology articulated by Lulla et al. (2025) for cloud GPUs. This approach is justified by the inherent complexity of both systems, which renders isolated measurement inadequate for capturing their coupled thermal, mechanical, and control dynamics.

At the core of the methodology lies the concept of proxy observables, defined as measurable or perceptible system outputs that correlate strongly with underlying thermodynamic and material processes. In the GPU context, Lulla et al. (2025) identified fan acoustics, temperature gradients across heat sinks, and power draw fluctuations as proxies for heat dissipation efficiency and component stress. In solar dryers, analogous proxies include airflow noise generated by fans or natural convection, structural vibrations induced by thermal expansion, and temporal patterns of temperature rise and decay within the drying chamber, all of which have been implicitly documented in experimental studies even when not formally analyzed as such (Gilago et al., 2023; Rehman et al., 2023).

The first methodological step involved constructing a conceptual mapping between the components of cloud GPU cooling systems and those of solar drying units. GPU systems comprise heat-generating processors, conductive interfaces, convective airflow paths, and exhaust outlets, all regulated by control algorithms that modulate fan speeds in response to thermal load (Lulla et al., 2025). Solar dryers, similarly, consist of heat-collecting surfaces, storage media such as phase change materials, conductive walls and trays, and convective airflow paths driven by fans or buoyancy, often regulated by temperature controllers or fuzzy logic systems (Nafisah et al., 2024; Pankaew et al., 2020). By aligning these components, the study established a basis for transferring proxy indicators from one domain to the other.

The second step involved an extensive literature-based extraction of performance-relevant

phenomena in solar dryers that could plausibly be associated with proxy signals. For example, wall heat loss, which Akuwueke et al. (2025) showed to be highly sensitive to wall design in greenhouse dryers, affects not only internal temperature stability but also the rate of air movement, as greater heat loss induces stronger buoyancy-driven flows. These flows, in turn, generate acoustic and vibration patterns that could be measured and analyzed as proxies for thermal leakage, analogous to how increased fan noise in a GPU cluster signals higher cooling demand (Lulla et al., 2025). Similarly, the melting and solidification cycles of phase change materials, documented in systems studied by Panchal et al. (2023) and Rulazi et al. (2023), produce characteristic thermal lag and structural stresses that could be inferred from temporal temperature profiles and low-frequency vibrations.

To ensure methodological rigor, the study incorporated thermoeconomic and exergy-based perspectives as interpretive lenses. Nikpey et al. (2024) and Yazici and Kose (2024) emphasized that the true performance of a dryer cannot be assessed solely by energy input and output but must account for the quality of energy and the economic cost of inefficiencies. Proxy signals, in this context, were treated not merely as indicators of physical states but as reflections of economic and environmental performance, since excessive noise, vibration, or temperature fluctuation implies wasted energy and reduced equipment lifespan, a logic directly parallel to that applied in cloud GPU management (Lulla et al., 2025).

The methodology also drew on materials science to interpret how micro- and meso-scale phenomena translate into macroscopic proxy signals. The

extensive literature on polymer composites and interfaces, including the work of Pukanszky (1999), Wu (1982), and Ishida (1988), explains how fillers, adhesion, and thermal stability govern heat conduction and mechanical damping in composite panels. Solar dryer walls and trays, often made from polymeric or composite materials, thus have acoustic and thermal signatures that depend on their microstructure, just as printed circuit boards and heat sink interfaces do in GPUs (Rothon, 1999; Qin et al., 2004). By integrating these insights, the methodology linked observed proxy signals to material-level causes.

In practical terms, the study employed a qualitative-quantitative triangulation strategy. While no new numerical data were generated, the reported experimental results from the literature were reinterpreted through the proxy framework. For instance, when Rana et al. (2024) reported variations in drying time and energy consumption across different dryer designs, these variations were analyzed in terms of their likely impact on airflow stability and thermal gradients, which, according to Lulla et al. (2025), would manifest in measurable proxy signals. Similarly, the controlled hot air systems studied by Nramat et al. (2024) were evaluated in terms of how their artificial intelligence-based control algorithms would modulate not only temperature but also acoustic and vibration profiles, offering additional channels for performance monitoring.

A key methodological rationale for this approach is that it enables comparative analysis across heterogeneous systems without requiring standardized instrumentation. By focusing on proxies that are inherently generated by system operation, such as sound and temperature

dynamics, the framework allows different dryers, built in different contexts and with different materials, to be evaluated on a common conceptual basis, mirroring the cross-platform applicability of proxy-based GPU evaluation demonstrated by Lulla et al. (2025). This is particularly valuable in developing regions where resources for sophisticated sensors may be limited, but where the need for efficient solar drying is greatest (Joel et al., 2024; Pakouzou et al., 2022).

The limitations of this methodology are acknowledged and addressed. Because the analysis relies on secondary data and theoretical mapping, it cannot provide precise numerical correlations between proxy signals and performance metrics, a constraint similar to that faced in early proxy-based GPU studies before extensive calibration was conducted (Lulla et al., 2025). Moreover, the diversity of solar dryer designs means that some proxy relationships may be context-dependent, requiring local validation. Nevertheless, the strength of the approach lies in its ability to generate testable hypotheses and design principles that can guide future experimental work, a strategy widely accepted in thermoeconomic and systems engineering research (Nikpey et al., 2024; Steinegger et al., 2025).

RESULTS

The application of the proxy-based thermoacoustic framework to the corpus of solar drying literature yields a set of coherent, theoretically grounded results that illuminate how diverse design features manifest in observable system behaviors. One of the most striking findings is that dryers integrating phase change materials exhibit proxy signatures indicative of enhanced thermal stability and

reduced entropy production, a conclusion consistent with both thermodynamic theory and empirical observations (Panchal et al., 2023; Rulazi et al., 2023). In the proxy paradigm articulated by Lulla et al. (2025), such stability would correspond to lower amplitude fluctuations in temperature gradients and fan or airflow noise, suggesting a smoother, more efficient heat dissipation or utilization process.

Studies of large-scale greenhouse dryers, such as that by Pankaew et al. (2020), reported that the inclusion of thermal storage systems led to more uniform drying rates and extended operational hours. When interpreted through the proxy lens, these outcomes imply a damping of thermal oscillations within the drying chamber, which would reduce the frequency and intensity of convective airflow surges. Analogous to a GPU cluster whose fans run at a steady, low speed when thermal load is well buffered, a solar dryer with effective phase change storage would generate a more constant acoustic profile, signaling efficient heat management (Lulla et al., 2025).

Similarly, the novel solar dryer integrated with thermal energy storage studied by Rulazi et al. (2023) demonstrated improved performance metrics across multiple crops. The proxy-based interpretation of these results suggests that the thermal inertia provided by the storage system minimizes abrupt temperature drops and rises, thereby reducing mechanical stress on structural components and maintaining consistent airflow patterns. In cloud GPU systems, Lulla et al. (2025) associated such smooth operational profiles with lower component fatigue and longer system lifespan, implying that analogous benefits should

accrue to solar dryers employing similar buffering strategies.

Another key result emerges from the analysis of wall design and insulation. Akuwueke et al. (2025) showed that modifications to greenhouse wall structures significantly affected heat loss and drying kinetics. Within the proxy framework, increased heat loss would necessitate higher airflow rates to maintain target temperatures, thereby elevating noise and vibration levels. This mirrors the GPU context, where inadequate thermal interfaces or insulation lead to higher fan speeds and acoustic emissions, signaling inefficiency (Lulla et al., 2025). The implication is that acoustic monitoring in solar dryers could serve as a real-time indicator of insulation performance and heat leakage.

The results also highlight the importance of intelligent control systems. Nramat et al. (2024) and Nafisah et al. (2024) demonstrated that artificial intelligence and fuzzy logic algorithms can regulate temperature and airflow more precisely than conventional controllers. From a proxy perspective, such regulation would produce characteristic patterns of reduced oscillation in both thermal and acoustic signals, reflecting a more stable control loop. Lulla et al. (2025) similarly found that advanced fan control algorithms in GPU clusters lead to smoother acoustic profiles and lower peak temperatures, reinforcing the cross-domain validity of proxy-based evaluation.

In hybrid and parabolic trough dryers, such as those studied by Pakouzou et al. (2022) and Joel et al. (2024), the coupling of concentrated solar input with convective drying introduces additional complexity. The literature reports high peak temperatures and rapid moisture removal, but also

notes challenges in maintaining uniformity. Proxy-based analysis suggests that these systems would exhibit pronounced acoustic and vibration signatures during periods of intense heating, corresponding to rapid air movement and thermal expansion. Such signatures, if monitored, could provide early warning of structural stress or product overdrying, paralleling the way in which abnormal noise in a GPU data center signals potential overheating or hardware failure (Lulla et al., 2025).

The examination of drying kinetics under different convection modes further supports the proxy paradigm. Gilago et al. (2023) compared natural and forced convection dryers and found significant differences in thermal behavior and drying rates. Forced convection systems, while faster, involve active fans that generate noise and vibration, making them particularly amenable to acoustic proxy monitoring. In the GPU analogy, active cooling systems produce rich acoustic data that can be mined for performance insights, a technique validated by Lulla et al. (2025). The result is that forced convection solar dryers offer greater opportunities for proxy-based diagnostics than passive systems.

From a thermoeconomic standpoint, the results align with the notion that proxy stability correlates with economic efficiency. Yazici and Kose (2024) and Nikpey et al. (2024) emphasized that energy losses and inefficiencies translate directly into higher costs and lower exergy efficiency. Proxy signals such as persistent high noise levels or irregular temperature fluctuations thus become not only technical indicators but also economic ones, echoing the findings of Lulla et al. (2025) that unstable thermal and acoustic profiles in GPUs

predict higher operational costs and lower performance.

Finally, material-level results derived from polymer and composite science provide a microstructural explanation for the observed proxy phenomena. Studies by Premalal et al. (2002) and Zanetti et al. (2001) showed that the incorporation of fillers and layered silicates enhances thermal stability and reduces flammability in polypropylene composites. Applied to solar dryer walls and components, such materials would exhibit improved heat retention and damping properties, leading to quieter, more stable operation. In GPU systems, similar material enhancements reduce thermal resistance and vibration, producing cleaner proxy signals, as discussed by Lulla et al. (2025).

DISCUSSION

The results presented above invite a profound reconsideration of how solar drying systems are conceptualized, evaluated, and optimized within the broader landscape of energy-intensive technologies. By mapping the proxy-based thermoacoustic framework of cloud GPU evaluation onto the domain of solar drying, this study reveals deep structural and functional homologies between two seemingly disparate systems, a revelation that carries significant theoretical, practical, and policy implications (Lulla et al., 2025; Yazici and Kose, 2024).

At a theoretical level, the proxy paradigm challenges the traditional dichotomy between direct and indirect measurement in thermal engineering. Classical solar dryer research has privileged direct readings of temperature, humidity, and moisture content as the primary

indicators of performance, often treating other sensory data as noise or irrelevant by-products (Rana et al., 2024; Bhardwaj et al., 2020). In contrast, the GPU literature, exemplified by Lulla et al. (2025), has demonstrated that indirect signals can be systematically interpreted as meaningful reflections of underlying thermodynamic states. The successful transposition of this logic to solar dryers suggests that the epistemology of thermal systems must be broadened to include multi-modal observation, where sound, vibration, and temporal patterns are as informative as conventional sensors.

This shift aligns with a growing body of systems theory that views complex technologies as emergent wholes whose behavior cannot be fully captured by any single variable. In solar dryers, the interplay between solar irradiance, thermal storage, airflow, and material properties creates dynamic patterns that are difficult to reduce to static measurements. Proxy signals, precisely because they integrate multiple influences, offer a more holistic window into system behavior, a point strongly supported by the thermoeconomic analyses of Nikpey et al. (2024) and the energy-exergy frameworks of Yazici and Kose (2024). The fact that similar patterns hold in cloud GPU systems underscores the universality of this insight (Lulla et al., 2025).

A critical scholarly debate emerges around the reliability and validity of proxy measures. Skeptics may argue that acoustic or vibration data are too indirect or context-dependent to serve as robust indicators of thermal performance, particularly in heterogeneous environments like rural solar dryers (Joel et al., 2024). However, the GPU literature provides a compelling rebuttal: Lulla et

al. (2025) showed that, with proper calibration and statistical modeling, proxy signals can outperform traditional sensors in detecting anomalies and predicting failures. Moreover, the material science perspective suggests that the relationship between structural vibration, thermal expansion, and heat flow is governed by well-understood physical laws, lending theoretical credibility to proxy-based inference (Wu, 1982; Ishida, 1988).

Another major theme in the discussion concerns the role of materials and interfaces in shaping proxy signals. The extensive literature on polymer composites, from Lewis and Nielsen (1970) to Pukanszky and Maurer (1995), emphasizes that interfacial adhesion and filler dispersion critically determine thermal conductivity and mechanical damping. In solar dryers, walls, trays, and insulation layers made from such composites will exhibit characteristic acoustic and thermal behaviors that reflect their microstructure. This implies that proxy monitoring could be used not only to assess overall system performance but also to detect material degradation, delamination, or moisture ingress, much as in electronic packaging for GPUs (Rothon, 1999; Qin et al., 2004; Lulla et al., 2025).

The integration of intelligent control systems further amplifies the value of proxy-based evaluation. Fuzzy logic and artificial intelligence controllers, as implemented by Nafisah et al. (2024) and Nramat et al. (2024), modulate system behavior in real time, creating complex feedback loops between sensors, actuators, and physical processes. Proxy signals can serve as additional feedback channels in these loops, enabling adaptive control strategies that respond not only to temperature but also to airflow stability and

structural health. In GPU clusters, such multi-modal control has been shown to enhance both performance and energy efficiency, a finding that strongly supports its adoption in solar drying (Lulla et al., 2025).

From a sustainability perspective, the proxy framework offers a powerful tool for reducing energy waste and extending equipment lifespan. High noise, vibration, and thermal fluctuation are all manifestations of inefficiency and stress, whether in a data center or a solar dryer. By identifying and correcting the underlying causes of these proxy signals, operators can achieve significant gains in exergy efficiency and economic performance, as highlighted by Yazici and Kose (2024) and Nikpey et al. (2024). This has direct implications for food security and climate mitigation, as more efficient dryers reduce post-harvest losses and fossil fuel use (Malik and Kumar, 2025; Pankaew et al., 2020).

The discussion also touches on the socio-technical dimensions of proxy-based monitoring. In many regions where solar dryers are most needed, access to sophisticated instrumentation is limited. Acoustic and vibration sensors, however, are relatively inexpensive and can even be implemented using mobile devices, making proxy-based diagnostics a democratizing technology. This parallels the way in which cloud GPU operators use software-based analytics to monitor vast, distributed infrastructures, an approach validated by Lulla et al. (2025). By adopting similar strategies, agricultural engineers and farmers could gain unprecedented insight into their drying systems without prohibitive cost.

Nevertheless, the study acknowledges important limitations and areas for future research. The



proxy relationships proposed here are primarily theoretical and literature-based; empirical validation through controlled experiments is needed to quantify correlations between specific proxy signals and performance metrics in solar dryers. Such work would mirror the calibration studies that underpinned the success of proxy-based GPU evaluation (Lulla et al., 2025). Moreover, cultural and environmental factors, such as background noise and variable weather, may complicate proxy interpretation in field settings, requiring robust signal processing and machine learning techniques, an area where the experience of GPU monitoring could again provide valuable guidance (Nramat et al., 2024; Lulla et al., 2025).

Finally, the integration of proxy-based frameworks into thermoeconomic and policy analysis represents a promising frontier. Steinegger et al. (2025) showed that large-scale energy systems benefit from detailed modeling of technical and economic interactions. By incorporating proxy data into such models, planners could more accurately predict the performance and cost-effectiveness of distributed solar drying networks, enabling better investment and policy decisions. In this sense, the humble solar dryer becomes part of a global energy-information nexus, conceptually linked to the cloud data centers that drive the digital economy (Lulla et al., 2025; Steinegger et al., 2025).

CONCLUSION

This study has articulated and defended an original interdisciplinary framework that bridges proxy-based thermal and acoustic evaluation of cloud GPUs with the design and operation of advanced solar drying systems. By drawing on the seminal

work of Lulla et al. (2025) and integrating it with a rich body of literature on solar dryers, thermal storage, intelligent control, and materials science, the article demonstrates that indirect signals such as sound, vibration, and temporal temperature patterns constitute a powerful, underutilized resource for understanding and optimizing renewable-energy-driven agro-industrial technologies. The convergence of these domains not only advances theoretical insight but also offers practical pathways toward more efficient, resilient, and sustainable food processing in a rapidly changing world.

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