

INNOVATION SCIENCE AND TECHNOLOGY

ISSUE 10, PART I / OCTOBER 2026

 **Acceptance of papers**



**Acceptance of
papers**

Published monthly



Topics

economics,
technology, social
sciences



EDITOR-IN-CHIEF:

Mirzaliyev Sanjar Makhamatjon ugli

DEPUTY EDITOR-IN-CHIEF:

Makhmudov Nosir Makhmudovich
DSc., Prof., Academician

DEPUTY EDITOR-IN-CHIEF:

Ochilov Bobur Bakhtiyor ugli – Senior
lecturer at TSUI

THE SCIENTIFIC-POPULAR ELECTRONIC
JOURNAL **"INNOVATION SCIENCE AND
TECHNOLOGY"** HAS BEEN REGISTERED
UNDER THE NUMBER **C-5669633** BY THE
AGENCY FOR INFORMATION AND MASS
COMMUNICATIONS (AOKA) OF THE
REPUBLIC OF UZBEKISTAN, EFFECTIVE
FROM OCTOBER 9, 2024.

CONTACTS

Phone: **+998 50 737 87 88**

Website: <https://ist-journal.uz>

Email: innovationist2025@gmail.com

The scientific electronic journal "Innovation Science and Technology" has been included in the list of scientific publications recommended for the publication of main scientific results of dissertations for the award of PhD and DSc degrees in economics and technical sciences, in accordance with the Resolution No. 370 of the Presidium of the Higher Attestation Commission of the Republic of Uzbekistan, dated May 8, 2025.

Editorial board:



Sharipov Kongiratbay Avezimbetovich,
Doctor of Technical Sciences (DSc), Professor



Abdurakhmanova Gulnora Kalandarovna, Doctor of
Economic Sciences (DSc), Professor



Cham Tat Huei,
Doctor of Philosophy (PhD), Professor (Malaysia)



Muhammad Imran Sadiq
Doctor of Philosophy in Economics (PhD), Professor,
Malaysia



Ahmed Aziz Ismail
Doctor of Technical Sciences (DSc),
Professor (Egypt)



Lee Chin
Doctor of Philosophy in Economics (PhD), (Malaysia)



Asongu Simplicie
Doctor of Philosophy in Economics (PhD), Cameroon



Rui Dang
Doctor of Chemistry (DSc), Professor, China



Zahoor Ahmed
Doctor of Philosophy in Economics (PhD), Turkey



Shujaat Abbas
Doctor of Philosophy in Economics (PhD), Russia



Tina A Coffelt
Doctor of Philosophy in Educational Sciences (PhD),
USA



Abdikarimova Dinara Rustamxanovna
Doctor of Economic Sciences (DSc), Professor

Kurbonbekova Mohichehra Turobjonovna
Doctor of Economic Sciences (DSc), Professor

Alimardonov Ilkhom Muzrabshokovich
Doctor of Economic Sciences (DSc), Professor



Razakova Barno Sayfieva
Doctor of Philosophy in Economics (PhD)



Khasanov Sarvar Ulugbek ugli
Doctor of Philosophy in Economics (PhD)



Kholikova Rukhsora Sanjarovna
Associate Professor (PhD)



Xoliyorova Shoxista Qahramon qizi
PhD in Economics, Assistant Lecturer at the Department TSUE

Nasiba G'anijon qizi Sattorova
PhD, Senior Lecturer at the Department of Banking

CONTENTS

IMPLEMENTATION OF THE IMPROVED METHODOLOGY IN PRACTICE AND ASSESSMENT OF ITS ECONOMIC EFFICIENCY	8
Eshniyazova Yulduz Yuldashbayevna	
EXPERIMENTAL OPTIMIZATION OF DESIGN AND ENERGY PARAMETERS OF A GARLAND-TURBINE MOBILE MICRO HYDROPOWER PLANT FOR FREE-FLOWING WATER	13
Sultonov Sanjarbe, Zokirov Islomjon, Nurillaev Ahadullo, Abdullaev Shavkat	
METHODOLOGY FOR INCREASING THE EFFICIENCY OF CREDIT OPERATIONS IN COMMERCIAL BANKS	19
Djumaniyazov Ikram Karimbaevich	
COMPARATIVE ANALYSIS OF A COMPACT RESIDUAL CONVOLUTIONAL MODEL AND LINEAR REGRESSION FOR IMAGE SUPER-RESOLUTION	27
Husan Arziqulov Normurod o'g'li	
COMPARATIVE EVALUATION OF MACHINE LEARNING ALGORITHMS AND CLASS IMBALANCE HANDLING STRATEGIES FOR CREDIT CARD FRAUD DETECTION	33
Mahmudova Dilnoza Avaz qizi	
DIGITAL TRANSFORMATION OF FINANCIAL RESOURCE MANAGEMENT IN PUBLIC SOCIAL SECTOR INSTITUTIONS	39
Khasanov Tulkin Axmatovich	
WAYS TO ENSURE THE STABILITY OF THE CAPITAL BASE OF COMMERCIAL BANKS	45
Isakov Isobek Janabay's son	
CROSS-DAY EXPERIMENTAL EVIDENCE OF THERMAL-LOAD SHIFTING IN A SOLAR-DRIVEN HYDRONIC RADIANT FLOOR WITH MACROENCAPSULATED RT52 PHASE CHANGE MATERIAL	50
Jurabek Kamolov, Sokhib Temirov, Marjona Makhmudova	
STUDY OF THE TRACTION DYNAMICS OF AN AGGREGATE CONSISTING OF A FRUIT-HARVESTING MACHINE AND ITS TWO-AXLE CONTAINER-CARRYING TRAILER PLATFORM	59
Norchayev Davron, Sardor Nigmatjonov, Norchayev Jaloliddin, Norchayev Rustam	
PRIORITY DIRECTIONS FOR STRENGTHENING THE FINANCIAL STABILITY OF AGRICULTURAL ENTERPRISES	67
Kulmatov Zafar Jumanazarovich	
METHODOLOGICAL APPROACHES TO DEVELOPING UNIVERSITY STUDENTS' DIGITAL COMMUNICATIVE COMPETENCE BASED ON EMOTIONAL INTELLIGENCE	73
Malikakhon Kamiljanova	
SIMULTANEOUS REMOVAL CHARACTERISTICS OF OIL AND HEAVY METAL IONS BY BIOFLOCCULANTS BASED ON THE CELLULOSE-DMAEMA/PEPA COMPOSITE	80
Xayitboeva Dilshoda, Ibragimov Nasrilla, Jumaev Anvarbek	
ECONOMIC ANALYSIS AND DEVELOPMENT STRATEGY OF THE WOOD-POLYMER COMPOSITES MARKET	84
Abdumalikova Zarnigor, Ayubova Indira, Jumaev Anvarbek	
ENERGY UTILIZATION ANALYSIS OF AGRICULTURAL DRYING BASED ON INTEGRATED SOLAR THERMAL AND PHOTOVOLTAIC ENERGY SUPPLY	89
Ibragimov Umidjon, Mirzayarova Sevara, Khujayorova Aziza	

ENERGY UTILIZATION ANALYSIS OF AGRICULTURAL DRYING BASED ON INTEGRATED SOLAR THERMAL AND PHOTOVOLTAIC ENERGY SUPPLY

Ibragimov Umidjon Khimatullayevich

DSc, Department of Energy Engineering, Karshi State Technical University

Mirzayarova Sevara Ubaydullayevna

PhD, Department of Energy Engineering, Karshi State Technical University

Khujayorova Aziza Farhod qizi

Researcher, Karshi State Technical University

Annotatsiya. Mazkur tadqiqotda quritish jarayonining asosiy issiqlik va yordamchi elektr energiyasiga bo'lgan ehtiyojini ta'minlash uchun quyosh issiqlik va fotoelektrik quyi tizimlari o'zaro muvofiqlashtirilgan qishloq xo'jaligi mahsulotlarini quritish texnologiyasining energetik samaradorligi o'rganilgan. Sonli modellashtirishga asoslangan yondashuvlardan farqli ravishda, mazkur tadqiqot quritish jarayonini belgilovchi asosiy energiya ko'rsatkichlarini energiya oqimlarini aniqlash, samaradorlikni baholash va qiyosiy talqin qilish asosida tahlil qilishga yo'naltirilgan. Quyosh energiyasining foydali issiqlik energiyasiga va fotoelektrik elektr energiyasiga taqsimlanishi, namlikni chiqarish uchun sarflanadigan energiya, yordamchi elektr energiyasi iste'moli, issiqlik akkumulyatori hissasi hamda natijaviy solishtirma energiya sarfiga alohida e'tibor qaratilgan. Quritish jarayonining real ish diapazonlarini aniqlash va jarayon darajasidagi ta'sirlarni texnologiyaga xos ta'sirlardan farqlash maqsadida e'lon qilingan eksperimental tadqiqotlar natijalari mezon sifatida foydalanilgan. Adabiyot ma'lumotlari quritish samaradorligi havo harorati va namligiga sezgir ekanligini, gibrid quyosh tizimlari esa ochiq quyoshda quritish bilan taqqoslaganda quritish davomiyligini qisqartirishi mumkinligini ko'rsatadi. Taklif etilgan tahliliy yondashuv integratsiyalashgan quyosh issiqlik–fotoelektrik quritgichning energetik samaradorligini baholash hamda yordamchi energiyaning ortiqcha sarfini oshirmagan holda quyosh energiyasidan foydalanishni kuchaytirish mumkin bo'lgan ish sharoitlarini aniqlash uchun ilmiy jihatdan izchil asos yaratadi. Tadqiqot muallifning o'z quritish qurilmasida keyingi eksperimental tekshiruvlarni amalga oshirish uchun tahliliy asos sifatida mo'ljallangan.

Kalit so'zlar: qishloq xo'jaligi mahsulotlarini quritish; quyosh issiqlik energiyasi; fotoelektrik konversiya; energiyadan foydalanish; solishtirma energiya sarfi; issiqlik samaradorligi; yordamchi elektr energiyasi; issiqlik energiyasini akkumulyatsiya qilish; energetik samaradorlikni baholash; qayta tiklanuvchi energiya integratsiyasi.

Аннотация. В исследовании рассматривается энергетическая эффективность технологии сушки сельскохозяйственной продукции, в которой солнечная тепловая и фотоэлектрическая подсистемы скоординированы для обеспечения основных тепловых и вспомогательных электрических потребностей процесса. В отличие от подходов, ориентированных преимущественно на численное моделирование, настоящее исследование основано на выявлении потоков энергии, оценке эффективности и сравнительной интерпретации основных энергетических показателей, определяющих процесс сушки. Особое внимание уделено распределению поступающей солнечной энергии между полезным тепловым вкладом и фотоэлектрической выработкой электроэнергии, энергии, необходимой для удаления влаги, потреблению вспомогательной электроэнергии, вкладу теплового аккумулирования и результирующему удельному энергопотреблению. Опубликованные экспериментальные данные используются в качестве ориентира для определения реалистичных рабочих диапазонов и разграничения эффектов на уровне процесса и эффектов, обусловленных конкретной технологией. Данные литературы показывают, что эффективность сушки чувствительна к температуре и влажности воздуха, тогда как гибридные солнечные системы могут сокращать продолжительность сушки по сравнению с сушкой на открытом солнце. Предложенная аналитическая основа обеспечивает научно обоснованный подход к оценке энергетической эффективности интегрированной солнечной тепловой–фотоэлектрической сушилки и выявлению условий эксплуатации, при которых использование солнечной энергии может быть интенсифицировано без увеличения избыточного потребления вспомогательной энергии. Работа предназначена в качестве аналитической основы для последующей экспериментальной валидации на собственной сушильной установке исследователя.

Ключевые слова: сушка сельскохозяйственной продукции; солнечная тепловая энергия; фотоэлектрическое преобразование; использование энергии; удельное энергопотребление; тепловая эффективность;

вспомогательная электроэнергия; аккумулярование тепловой энергии; оценка энергетической эффективности; интеграция возобновляемых источников энергии.

Abstract. The study examines the energy performance of an agricultural drying technology in which solar thermal and photovoltaic subsystems are coordinated to supply the principal thermal and auxiliary electrical demands of the process. Unlike approaches centred on numerical modelling, the present work is structured around energy-flow identification, performance assessment and comparative interpretation of the principal energy indicators governing drying operation. Particular attention is given to the partitioning of incident solar energy into useful thermal input and photovoltaic electricity, the energy required for moisture removal, auxiliary electricity consumption, thermal-storage contribution and the resulting specific energy consumption. Published experimental evidence is used as a benchmark to establish realistic operating ranges and to distinguish process-level effects from technology-specific effects. Literature data demonstrate that drying performance is sensitive to air temperature and humidity, while hybrid solar systems can shorten drying duration relative to open-sun operation. The proposed analytical framework provides a scientifically consistent basis for evaluating the energy efficiency of an integrated solar thermal–photovoltaic dryer and for identifying operating conditions under which solar energy utilization can be intensified without increasing unnecessary auxiliary consumption. The work is intended as an analytical foundation for subsequent experimental validation on the researcher's own drying installation.

Keywords: agricultural drying; solar thermal energy; photovoltaic conversion; energy utilization; specific energy consumption; thermal efficiency; auxiliary electricity; thermal energy storage; energy performance assessment; renewable-energy integration.

INTRODUCTION

Agricultural drying is an energy-intensive post-harvest operation in which moisture removal must be achieved with sufficient process stability while avoiding excessive thermal and electrical expenditure. The energy requirement is determined not only by the quantity of moisture removed but also by the temperature and humidity of the drying air, the duration of exposure, heat losses from the equipment, and the electricity consumed by air-circulation and control components [1–4]. Consequently, an assessment based solely on drying time is insufficient for determining the technological value of a drying system; the energy pathways that produce that drying effect must also be quantified.

Solar thermal technology directly addresses the thermal component of drying demand by converting incident solar radiation into useful heat. Its principal limitation is the temporal variability of solar availability. During periods of reduced irradiance, the thermal input can decline rapidly, causing unstable drying conditions or forcing the use of auxiliary energy. Thermal energy storage can mitigate this discontinuity by shifting part of the collected heat from high-resource periods to periods of insufficient solar input [5,6]. Photovoltaic conversion addresses a different component of the energy balance. Fans, sensors, controllers, and monitoring devices require electricity even when process heat is supplied by solar radiation. Therefore, integrating photovoltaic generation with the thermal subsystem creates an opportunity to match two distinct energy demands with two complementary conversion pathways. The thermal subsystem should be evaluated according to useful heat delivery, whereas the PV subsystem should be assessed according to electrical yield and the extent to which it offsets auxiliary demand. Recent experimental research on hybrid solar drying has demonstrated that the energetic assessment of a dryer can be extended beyond simple thermal efficiency by considering total energy input, specific energy consumption, exergy-related indicators, environmental effects, and economic performance. One 2026 study reported drying durations of 12–18 h for 5-mm agricultural samples in a solar–biomass hybrid system, compared with 28–36 h for open-sun drying, while reporting thermal efficiency in the range of 19.5–23.2% [7]. These values are not transferred to the present system as experimental results; they are used only as literature benchmarks demonstrating the importance of a multidimensional energy assessment.

The scientific problem addressed in this article is the insufficient separation of thermal and electrical energy pathways in the evaluation of integrated solar drying. The objective is to establish an analytical assessment structure in which solar thermal input, PV electricity, auxiliary consumption, moisture-removal demand, and thermal-storage contribution are considered within one coherent performance framework.

LITERATURE REVIEW

Research on the energy efficiency of agricultural drying has addressed a wide range of issues, including drying kinetics, heat and mass transfer, energy consumption, solar thermal utilization, renewable-energy integration, and thermal energy storage. The existing literature indicates that drying performance cannot be adequately evaluated solely in terms of drying time or thermal efficiency. A comprehensive assessment should also consider the total energy input, energy required for moisture removal, auxiliary electricity consumption, and the contribution of renewable energy sources.

Berk [8] provides a comprehensive treatment of dehydration processes in food engineering, including the

fundamental principles governing heat and mass transfer during drying. The work demonstrates that the energy requirement of a drying process depends not only on the amount of moisture removed but also on the physical characteristics of the product and the operating conditions. These principles provide a theoretical basis for evaluating the energy required for moisture removal and support the use of specific energy consumption as an important indicator for assessing agricultural drying systems.

Calín-Sánchez et al. [9] investigated the drying kinetics and energy consumption associated with the dehydration of pomegranate arils and rind. Their results demonstrate the relationship between drying conditions, moisture removal kinetics, and energy consumption. The study emphasizes the importance of considering the temporal evolution of moisture content rather than evaluating only the final moisture level. This approach is particularly relevant to solar drying systems, where drying-air temperature, relative humidity, and airflow may vary considerably during operation.

Dincer and Hussain [10] developed a correlation-based approach for describing the drying behavior of solid materials. Their work contributes to the understanding of the relationship between heat and mass transfer phenomena during drying. From an energy-performance perspective, such approaches demonstrate the importance of linking the moisture state of the product and drying conditions with the energy required by the process. However, these approaches primarily address the kinetics and physical behavior of drying and do not fully address the simultaneous contribution of solar thermal and photovoltaic subsystems within an integrated energy balance.

Defraeye [11] reviewed advanced computational modeling approaches for drying processes and highlighted the interactions among heat transfer, mass transfer, airflow, and product properties. The study demonstrates that drying should be considered as a coupled and multidimensional process rather than as an isolated heat-transfer operation. Consequently, the energy performance of a dryer should be evaluated at the system level, taking into account the distribution of energy throughout the complete technological chain rather than considering only the efficiency of an individual heat source.

One of the major challenges associated with solar drying is the temporal variability of solar radiation. Thermal energy storage is therefore an important component for reducing the mismatch between solar-energy availability and process demand. Zhang et al. [12] investigated heat-transfer enhancement in a shell-and-tube latent heat thermal energy storage system using metal foam and fins. Their results demonstrate that improvements in heat-transfer characteristics can enhance the useful thermal performance of storage systems. This is relevant to solar drying because improved heat transfer can increase the effectiveness with which collected solar energy is subsequently delivered to the drying process.

Zhang and Yan investigated the discharge performance of a molten salt/ceramic foam composite phase-change material in a shell-and-tube latent heat thermal energy storage system. Their work demonstrates that the practical performance of thermal storage depends not only on nominal storage capacity but also on the ability to deliver stored heat under actual operating conditions. For solar drying applications, this suggests that thermal storage should be assessed according to its contribution to maintaining useful drying conditions and reducing dependence on external energy rather than solely according to its nominal energy capacity.

Huang, Chen, and Phool investigated a copper-enhanced hybrid solar–biomass drying technology for agricultural processing. The study reported drying durations of 12–18 h for 5-mm samples, compared with 28–36 h for open-sun drying. Thermal efficiency was reported in the range of 19.5–23.2%, while total energy input ranged from 6.1 to 38.2 MJ and specific energy consumption.

The objective of the study is to substantiate an energy-performance assessment approach for an agricultural drying device supplied by integrated solar thermal and photovoltaic energy. The approach is designed to reveal where useful energy is generated, where energy is consumed, and which operating variables determine the efficiency of the complete technological chain.

- to distinguish the thermal and electrical energy pathways within an integrated solar drying system;
- to establish a set of energy-performance indicators suitable for experimental evaluation of the dryer;
- to interpret the influence of drying-air temperature, relative humidity, airflow, and solar-resource variability from an energy-efficiency perspective;
- to assess the role of thermal storage in reducing the mismatch between solar heat availability and process demand;
- to develop a comparative basis for evaluating energy saving and energy autonomy after integration of the PV subsystem.

RESEARCH METHODOLOGY

The methodological basis of the present work is an energy-flow analysis rather than numerical simulation. The system boundary encompasses the solar thermal collector, thermal storage unit where applicable, drying

chamber, air-circulation equipment, PV subsystem, electrical control components, and agricultural product. Solar radiation is treated as the primary renewable input, while useful heat supplied to the drying air and electricity delivered to auxiliary loads are treated as distinct output pathways (Fig.1.).

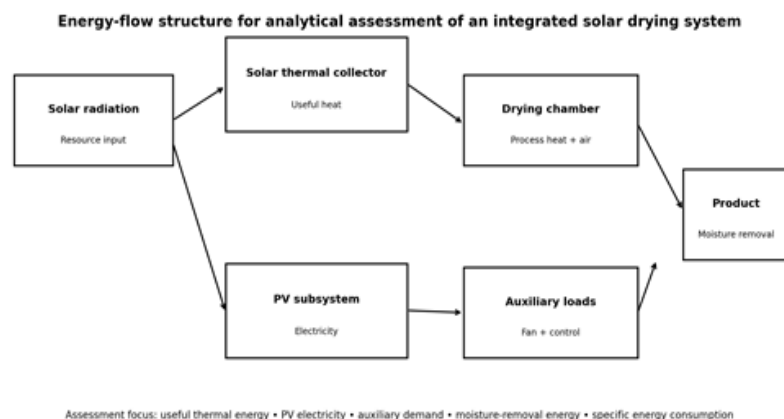


Figure 1. Energy-flow structure used for assessment of an integrated solar thermal–PV drying system.

Energy-flow decomposition. The energy analysis separates the system into five principal flows: (i) incident solar energy; (ii) useful thermal energy transferred from the collector to the drying process; (iii) electrical energy generated by the PV subsystem; (iv) energy required for moisture removal from the product; and (v) auxiliary electricity consumed by fans, control and monitoring equipment. This decomposition prevents double counting and makes it possible to identify whether a change in drying performance originates from increased useful heat delivery, reduced losses, reduced auxiliary demand or improved moisture-removal effectiveness. The thermal contribution is interpreted through the relationship between available solar energy and the useful heat actually delivered to the drying air. The electrical contribution is evaluated through PV energy production and the fraction of auxiliary electricity that can be supplied without external grid energy. The combined system is consequently assessed not by simply adding thermal and electrical efficiencies, but by examining the degree of energy substitution and the reduction of external energy dependence (Table 1.).

Table 1.
Principal performance indicators

Indicator	Assessment meaning	Required measurements	Interpretation
Useful thermal output	Heat effectively delivered to drying air/product	Collector inlet/outlet temperature, airflow, operating time	Indicates thermal conversion effectiveness
PV electrical yield	Electricity generated for auxiliary equipment	PV voltage/current or energy meter, operating time	Indicates electrical contribution
Auxiliary electricity demand	Electricity consumed by fans and control	Fan/controller power and operating time	Shows non-thermal energy burden
Specific energy consumption	Energy expenditure per unit of moisture removed	Mass loss, thermal/electrical energy	Core process-level efficiency indicator
Drying duration	Time required to reach target moisture	Mass/moisture measurements over time	Indicates process intensity but not energy efficiency alone
Solar fraction	Share of process demand covered by solar energy	Solar thermal and PV energy, external energy	Indicates energy autonomy
Overall energy utilization	Relationship between useful process effect and total renewable input	All principal energy flows	Integrates thermal and electrical pathways

Comparative assessment logic. Three reference configurations are analytically distinguished: a conventional drying arrangement dependent on external energy; a solar-thermal drying arrangement in which process heat is renewable but auxiliary electricity remains externally supplied; and an integrated solar

thermal–PV arrangement in which both the dominant thermal demand and a substantial share of the auxiliary electrical demand are supplied by solar energy. The purpose of this comparison is not to rank technologies universally, but to isolate the incremental energy effect attributable to subsystem integration. For experimental implementation, measurements should be synchronized in time so that solar irradiance, ambient temperature, drying-air temperature, relative humidity, airflow, product mass and electrical power are recorded over the same operating intervals. This permits the energy balance to be evaluated on an hourly or shorter time basis and subsequently aggregated for each complete drying cycle. Such synchronization is particularly important because solar resource, thermal-storage state and product moisture evolve simultaneously.

ANALYSIS AND RESULTS

Literature-derived energetic benchmarks. The available literature provides evidence that energy performance should be interpreted jointly with drying kinetics. In the 2025 study of pomegranate arils, drying experiments were conducted at 30, 40, 50 and 60 °C, with an air velocity of 0.5 m/s and ambient relative humidity of 52%. Increasing drying-air temperature increased the drying constant, indicating a stronger drying driving force. These observations support the inclusion of drying-air temperature and humidity as principal explanatory variables in the energy assessment of a solar dryer. They do not constitute measurements of the present integrated solar thermal–PV device. A separate 2026 experimental investigation of a copper-enhanced solar–biomass drying system reported 12–18 h drying duration for 5-mm samples, compared with 28–36 h for open-sun drying. The reported thermal efficiency was 19.5–23.2%, while total energy input for complete drying ranged from 6.1 to 38.2 MJ and the reported specific energy consumption ranged from 4.8 to 28.5 kWh per kilogram of moisture extracted. Because that system incorporated biomass as a backup source, these values should be regarded as comparative benchmarks rather than transferable performance values for a solar thermal–PV dryer (Table 2).

Table 2.
Literature-derived energetic benchmarks

Literature benchmark	Reported value	System context	Use in present study
Drying duration	12–18 h	Solar–biomass hybrid dryer; 5-mm samples	Reference range for process duration
Open-sun duration	28–36 h	Same comparative study	Baseline for weather-dependent drying
Thermal efficiency	19.5–23.2%	Solar–biomass hybrid dryer	Benchmark for thermal subsystem assessment
Total energy input	6.1–38.2 MJ	Complete drying operations	Order-of-magnitude literature benchmark
Specific energy consumption	4.8–28.5 kWh/kg moisture	Hybrid dryer	Reference indicator for future measurements

Note: Source: Huang, Chen, and Phool [7].

Thermal subsystem: useful heat as the primary process driver. For an agricultural dryer, the solar thermal subsystem should be evaluated according to the amount and temporal stability of useful heat delivered to the drying air rather than according to collector temperature alone. A high collector temperature does not automatically imply high process efficiency if useful heat transfer to the airflow is accompanied by substantial thermal losses. Accordingly, the decisive measurement is the useful thermal output under actual airflow and operating conditions. The analysis also indicates that thermal stability is energetically significant. Excessively fluctuating drying-air temperature can prolong the process and increase the duration for which fans and control devices remain active. Thermal storage can therefore provide an indirect energy benefit in addition to its direct heat-storage function: by smoothing the thermal supply, it can reduce periods of low drying intensity and improve the utilization of already-collected solar energy.

Photovoltaic subsystem: reduction of auxiliary energy dependence. The PV subsystem has a distinct energetic role because it does not replace the thermal requirement of moisture evaporation; instead, it offsets electrical consumption associated with air movement, sensing and control. This distinction is essential for rigorous energy accounting. The PV contribution should therefore be expressed as the electrical energy generated during the drying cycle and the corresponding share of auxiliary electricity demand supplied by the PV subsystem. A 2026 hybrid-dryer study explicitly proposed photovoltaic panels for powering circulation fans

as a future development pathway, combined with solar thermal collection and backup heating. This supports the conceptual relevance of PV integration while also demonstrating that PV sizing should be linked to the actual auxiliary load rather than to the thermal load of the dryer.

Integrated energy utilization. The principal scientific value of integration lies in the complementary allocation of solar energy. Solar thermal conversion addresses the high-energy thermal pathway, while photovoltaic conversion addresses the lower-power but continuously required electrical pathway. When these subsystems are coordinated, the same solar resource can support both moisture removal and the operation of the equipment needed to sustain the drying process. From an energy-efficiency perspective, the integrated configuration should therefore be judged by the reduction in external energy requirement per unit of moisture removed. A decrease in electricity consumption alone is insufficient if thermal losses increase; likewise, a high thermal efficiency is insufficient if the dryer remains heavily dependent on external electricity. The appropriate system-level indicator is consequently the combined energy burden of the complete drying cycle, normalized to the useful drying effect.

Role of thermal storage under variable solar availability. Solar resource intermittency creates a mismatch between the timing of energy availability and the timing of process demand. Thermal storage can partially decouple these two variables. During high-irradiance periods, surplus useful heat can be accumulated; during declining irradiance, stored heat can support the drying-air temperature and reduce the need for external heating. The literature on solar energy storage emphasizes the importance of storage configuration and heat-transfer characteristics for maintaining useful thermal output under fluctuating conditions. For the proposed drying application, storage should not be evaluated solely by nominal energy capacity. Its practical value depends on charging and discharging behaviour, thermal losses, the temperature range compatible with the product, and the degree to which stored heat actually reduces external energy demand. Therefore, storage performance should be reported as a process-level contribution to energy saving rather than as an isolated material property (Table 3.).

Table 3
Energy-performance matrix for future experimental validation

Measurement block	Variables	Sampling priority	Primary indicator	Scientific purpose
Solar resource	Irradiance, ambient temperature	Continuous	Solar input	Characterize renewable resource
Thermal collector	Air inlet/outlet temperature, airflow	Continuous	Useful thermal output	Quantify heat delivery
PV subsystem	Voltage, current, electrical energy	Continuous	PV yield	Quantify electrical contribution
Drying process	Product mass/moisture, air temperature, RH	Periodic + continuous	Moisture-removal rate	Relate process response to energy input
Auxiliary loads	Fan/control power	Continuous	Auxiliary electricity	Quantify electrical burden
System boundary	External energy, renewable energy	Per cycle	Specific energy consumption	Assess integrated efficiency

Note: Compiled by the authors for future experimental validation.

The scientific novelty of the present work is the formulation of an integrated energy-performance perspective in which the thermal and electrical pathways of a solar dryer are evaluated simultaneously but not conflated. The approach separates useful thermal delivery from auxiliary electricity production and then reconnects both pathways at the level of total external energy dependence and specific energy consumption. This provides a more discriminating assessment of the contribution of PV integration than reporting collector efficiency or PV efficiency independently.

The practical significance lies in establishing a measurement architecture that can be directly implemented on an experimental prototype. The framework supports identification of dominant energy losses, determination of the contribution of thermal storage, assessment of PV self-supply for auxiliary loads and selection of operating regimes that improve energy utilization. It is therefore directly applicable to the PhD research objective of increasing the energy efficiency of an agricultural drying device through integrated solar thermal and photovoltaic energy supply.

The numerical values cited in this article are literature-derived benchmarks and are not presented as measurements obtained from the authors' own solar thermal–PV dryer. Consequently, the present manuscript does not claim an experimentally determined overall efficiency, PV yield, collector efficiency or energy saving

percentage for the researcher's device. Such values must be obtained from synchronized measurements on the actual prototype.

The next experimental stage should include repeated drying cycles under different solar-resource conditions and, where feasible, a reference configuration without PV support. The comparison should retain the same product loading, target moisture content and principal operating conditions so that the incremental contribution of subsystem integration can be isolated. Measurement uncertainty should be reported for irradiance, temperature, humidity, airflow, mass and electrical power, because uncertainty in these variables propagates into the calculated energy indicators.

CONCLUSIONS AND RECOMMENDATIONS

The energy efficiency of an agricultural dryer integrating solar thermal and photovoltaic technologies should be assessed through the complete energy pathway rather than through a single component efficiency. Solar thermal conversion supplies the principal process heat, whereas PV conversion primarily offsets the electrical demand of fans, monitoring and control equipment; these contributions should therefore be quantified separately before system-level integration. Specific energy consumption per unit of moisture removed is a particularly informative system-level indicator because it connects renewable-energy input with the actual technological effect of drying. Thermal storage has strategic value under variable solar availability because it can improve the temporal matching between collected solar heat and drying demand, thereby reducing reliance on external energy. Published experimental evidence confirms that drying-air temperature, humidity and solar-resource variability materially influence drying performance; however, the reported values of other systems cannot be treated as performance results for the present prototype. The analytical framework developed here provides a rigorous basis for subsequent experimental evaluation of the researcher's integrated solar thermal–PV drying device and for quantifying energy saving, energy autonomy and overall energy utilization.

REFERENCES

1. Berk, Z. (2009). Dehydration. In *Food Process Engineering and Technology* (pp. 459–510). Academic Press. DOI: <https://doi.org/10.1016/B978-0-12-373660-4.00022-3>
2. Calín-Sánchez, Á., Figiel, A., Szarycz, M., Lech, K., Nuncio-Jáuregui, N., & Carbonell-Barrachina, Á. A. (2014). Drying kinetics and energy consumption in the dehydration of pomegranate arils and rind. *Food and Bioprocess Technology*, 7, 2071–2083. DOI: <https://doi.org/10.1007/s11947-013-1222-5>
3. Dincer, I., & Hussain, M. M. (2002). Development of a new bi–Di correlation for solids drying. *International Journal of Heat and Mass Transfer*, 45(15), 3065–3069. DOI: [https://doi.org/10.1016/S0017-9310\(02\)00040-9](https://doi.org/10.1016/S0017-9310(02)00040-9)
4. Defraeye, T. (2014). Advanced computational modelling for drying processes – A review. *Applied Energy*, 131, 323–344. DOI: <https://doi.org/10.1016/j.apenergy.2014.06.027>
5. Zhang, S., Li, Z., Yan, Y., Alston, M., & Tian, L. (2023). Comparative study on heat transfer enhancement of metal foam and fins in a shell-and-tube latent heat thermal energy storage unit. *Energy Storage and Saving*, 2(3), 487–494. DOI: <https://doi.org/10.1016/j.enss.2023.03.004>
6. Zhang, S., & Yan, Y. (2022). Evaluation of discharging performance of molten salt/ceramic foam composite phase change material in a shell-and-tube latent heat thermal energy storage unit. *Renewable Energy*, 198, 1210–1223. DOI: <https://doi.org/10.1016/j.renene.2022.08.124>
7. Huang, M., Chen, Q., & Phool, D. (2026). Performance optimization towards sustainable agricultural processing: Copper enhanced hybrid solar biomass drying technology helps China's rural energy conservation and emission reduction. *Case Studies in Thermal Engineering*, 83, 108190. DOI: <https://doi.org/10.1016/j.csite.2026.108190>
8. Maphosa, B., Tsige, A. A., & Opara, U. L. (2025). Optimizing pomegranate aril drying: CFD-based heat and mass transfer analysis. *Journal of Food Process Engineering*, 48, e70109. DOI: <https://doi.org/10.1111/jfpe.70109>
9. Hayek, M., Assaf, J., & Lteif, W. (2011). Experimental investigation of the performance of evacuated-tube solar collectors under eastern Mediterranean climatic conditions. *Energy Procedia*, 6, 618–626. DOI: <https://doi.org/10.1016/j.egypro.2011.05.071>
10. Chow, T.-T., Bai, Y., Dong, Z., & Fong, K.-F. (2013). Selection between single-phase and two-phase evacuated-tube solar water heaters in different climate zones of China. *Solar Energy*, 98, 265–274. DOI: <https://doi.org/10.1016/j.solener.2013.10.011>
11. Azad, E. (2018). Experimental analysis of thermal performance of solar collectors with different numbers of heat pipes versus a flow-through solar collector. *Renewable and Sustainable Energy Reviews*, 82, 4320–4325. DOI: <https://doi.org/10.1016/j.rser.2017.10.015>
12. Shafieian, A., Khiadani, M., & Nosrati, A. (2019). Thermal performance of an evacuated tube heat pipe solar water heating system in cold season. *Applied Thermal Engineering*, 149, 644–657. DOI: <https://doi.org/10.1016/j.applthermaleng.2018.12.078>

Proofreader: Zokir ALIBEKOV

Layout and Designer: Oloviddin Sobir ugli

2026. № 10

© When materials are reproduced, the INNOVATION SCIENCE AND TECHNOLOGY journal must be cited as the source. Authors are responsible for the accuracy of the information in materials and advertisements published in the journal. Editorial opinions may not always align with those of the authors. Submitted materials will not be returned to the editorial office.

To publish articles in this journal, you may submit articles, advertisements, stories, and other creative materials through the following links. Materials and advertisements are published on a paid basis.

You may subscribe to the journal at any time using the following details. Once subscribed, please send a screenshot or photo of your payment confirmation to our Telegram page @iqtisodiyot_77. Based on this, we will send the latest issue of the journal to your address each month.

“The journal “INNOVATION SCIENCE AND TECHNOLOGY” has been registered by the Agency for Information and Mass Communications under the Administration of the President of the Republic of Uzbekistan from 09.10.2024 under the registration number №390637. License number: C-5669633. PNFL: 30407832680027

Our address: Tashkent city, Yunusobod district, 19th block,
House 17.



Acceptance of articles

Published every
monthly



Directions

Social, economic, political,
technological, scientific



Scopus || Scientific electronic journal specializing in Scopus

CERTIFICATE NUMBER: №390637

**ORDER NUMBER ACCORDING TO
THE LICENSE REGISTER: C-5669633**

CONTACT:



Contact us
+998 50 737 87 88



Telegram channel
t.me/scopus_IST2100



Journal official website
<https://ist-journal.uz/index.php/IST>