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Article

SOLNIDO: Un modelo innovador de incubadora solar para la producción sostenible de pollos

SOLNIDO: A novel solar-powered incubator model for advancing sustainable poultry farming

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Abstract

This article presents SolNido, an innovative solar incubator model designed to promote sustainable poultry production in rural and urban communities. The prototype integrates photovoltaic energy, an autonomous electrical storage system, and automatic control of temperature and humidity to ensure optimal incubation conditions. Field tests conducted in San Juan del Río, Querétaro, validated its feasibility, maintaining stable conditions (37.5 ± 0.5 °C and 50–55% relative humidity) and achieving a 20% hatching rate using non-certified eggs. Although preliminary, projections indicate that success rates could exceed 70% when employing certified fertile batches. Beyond its technical performance, SolNido provides strategic advantages such as a 95% reduction in grid energy dependence, significant annual savings in operating costs, and environmental benefits equivalent to preventing 0.14 tons of CO_2 emissions per year. This development underscores the potential of renewable energy innovation in agriculture as a viable pathway to create sustainable, resilient, and socially impactful production systems.

Solar energy, poultry incubation, sustainability

Resumen

Este artículo presenta SolNido, un modelo innovador de incubadora solar diseñado para impulsar la producción avícola sostenible en comunidades rurales y urbanas. El prototipo integra energía fotovoltaica, un sistema autónomo de almacenamiento eléctrico y control automático de temperatura y humedad para asegurar condiciones óptimas de incubación. Las pruebas de campo realizadas en San Juan del Río, Querétaro, validaron su factibilidad, manteniendo condiciones estables (37.5 ± 0.5 °C y 50–55% de humedad relativa) y alcanzando una tasa de eclosión del 20% con huevos no certificados. Aunque preliminares, las proyecciones indican que el éxito podría superar el 70% al emplear lotes fértiles certificados. Más allá de su desempeño técnico, SolNido ofrece ventajas estratégicas como una reducción del 95% en la dependencia de la red eléctrica, ahorros anuales significativos en costos de operación y beneficios ambientales equivalentes a evitar la emisión de 0.14 toneladas de CO_2 por año. Este desarrollo subraya el potencial de la innovación en energías renovables aplicada a la agricultura como vía viable hacia sistemas productivos sostenibles, resilientes y de alto impacto social.

Energía solar, incubación avícola, sostenibilidad

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

Poultry farming is one of the strategic sectors of food production worldwide. Mexico ranks high in chicken and egg consumption, accounting for more than 37% of the national livestock GDP. However, the incubation process, a key stage for productivity, depends largely on conventional electric incubators that require high energy consumption and, in many cases, generate dependence on fossil fuels.

In 2023-2024, the poultry sector in Querétaro generated a production value of more than 16.203 billion pesos, consolidating itself as a strategic pillar of the local economy, with the municipalities of Tequisquiapan, Ezequiel Montes and Colón as the main contributors (Elsitio Avícola; OEM).

At the national level, Querétaro ranks among the top five producers of chicken meat, along with states such as Veracruz, Jalisco, and Aguascalientes (Unión Nacional de Avicultores; Elsitio Avícola).

The Mexican poultry industry accounts for almost 37% of the national livestock GDP, underscoring its role as one of the most dynamic livestock activities in the country. The state of Querétaro contributes significantly to this dynamic (National Union of Poultry Farmers).

At the local level, there are farms located in rural areas of Querétaro that are advancing with a technological vision, such as the Huevo Santiago company, which is committed to regional development and strengthening the local poultry industry (Huevo Santiago).

Climate change, energy price volatility and the need for autonomy in rural communities make the development of clean, accessible and replicable technologies essential.

Mexico has exceptional solar potential, with average irradiation levels exceeding 5 kWh/m² per day in most of the country, positioning it as one of the countries with the greatest comparative advantages for the use of solar energy. In states such as Querétaro, annual irradiation favours the development of photovoltaic projects and decentralised applications, enabling innovative solutions in productive sectors such as poultry farming.

This availability of solar resources makes photovoltaic energy a viable and sustainable alternative for promoting energy autonomy and reducing dependence on fossil fuels in rural communities.

Box 1

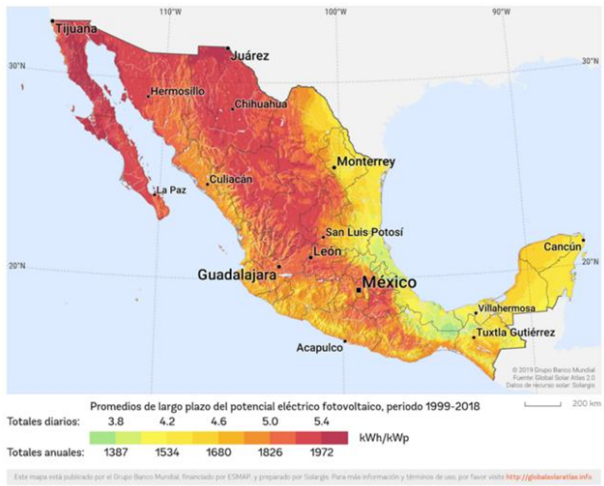

Figure 1

Solarama. (n.d.). Solar radiation in Mexico
https://solarama.mx/blog/radiacion-solar-en-mexico/

In this context, SolNido emerges: an innovative solar incubator that combines sustainability, efficiency and low operating costs, offering a viable alternative for small and medium-sized producers.

2. Background

The first studies on solar incubators date back to Rubio Picó (1979), who proposed the use of solar thermal panels to replace electric heating in incubators, achieving thermal stability and reducing energy costs. Decades later, García-Hierro Navas (2016) developed a system based on solar thermal collectors applied to the incubation of red-legged partridges, also incorporating smart sensors to monitor biological activity, which allowed for more precise control of temperature and humidity with lower electricity consumption.

In 2019, Corzo Hernández designed and built a low-cost automated incubator at the Technological Institute of Tuxtla Gutiérrez, with a capacity for 30 eggs and controlled by Arduino, which improved incubation efficiency and guaranteed the availability of national spare parts, as well as contributing to the preservation of wild species in UMAs.

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Subsequently, Monta Toapanta (2020) presented a fuzzy control and monitoring system for poultry farms, using solar-powered underfloor heating, which provided an innovative vision of intelligent automation and energy efficiency in poultry production.

Along the same lines, Yerovi Parra (2021) implemented a monitoring and control system with IoT technology applied to chicken incubators in Ecuador, enabling remote supervision of critical parameters and optimisation of the incubation process through digital platforms.

A year later, Franco Sánchez (2022) designed a semi-automatic artisanal incubator for Creole eggs in Ecuador, highlighting the relevance of low-cost solutions adapted to the rural context. In this context, SolNido emerges: an innovative solar incubator that combines sustainability, efficiency and low operating costs, offering a viable alternative for small and medium-sized producers.

Box 2

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Complementarily, Hernández Elizondo (2023) addressed the breeding and management of laying hens with a sustainable approach, highlighting responsible production practices that strengthen food security and economic resilience in rural communities. More recently, Romero Pisco, Pérez Cubillos, Pardo Pedraza and Quiñonez Puentes (2025) developed a solar photovoltaic poultry incubator focused on mitigating the effects of power outages, ensuring the continuity of the production process in rural communities in Colombia.

This evolution shows that the application of renewable energies, intelligent automation, sustainable practices, and digital technologies in poultry incubation is technically and socially viable, with different approaches: from solar thermal energy, through digitisation via IoT and low-cost artisanal solutions, to comprehensive models of sustainable production. In this context, SolNido (2025) represents an innovative leap forward by integrating photovoltaic energy, automated control and electrical storage, offering greater autonomy, scalability and replicability in rural areas with limited access to electricity, thereby strengthening food security and productive sustainability.

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3. Methodology

The research was carried out using an applied experimental approach, divided into four phases:

1. Conceptual design: incubation requirements were established (37.5 °C, 50–55% relative humidity, automatic turning every 2 hours).

2. Energy sizing: calculation of the incubator's electricity consumption (35 W, 24 hours/day, 48 hours of autonomy).

The energy balance was calculated as:

$$Ed = Pc \times t = 35W \times 24h = 840\ Wh/day$$

For photovoltaic sizing:

$$Npv = (Ed/(HSP \times Pmod \times \eta)) = ((840/(5\times100\times0.8)) \approx 2.1 \text{ modules}$$

The initial prototype was operated with 1 module (100 W) and a 110 Ah battery, validating minimum viability.

3. Prototype construction: integration of automatic temperature and humidity control systems, thermally insulated incubation chamber, ventilation system, and turning mechanisms.

4. Experimental testing: incubation of 20 eggs in the UTSJR renewable energy laboratory, with temperature, humidity, and ovoscopy monitoring.

Fig. 2. Electrical diagram of the photovoltaic system implemented in the SolNido prototype. Source: Own elaboration, 2024.

Commercial components that are easily accessible on the domestic market were used in the construction of the SolNido prototype. The charge control system consisted of a generic PWM solar controller with an integrated LCD screen, 5 V USB outputs and basic protection functions (microprocessor control, voltage adjustment, built-in timer and total protection). This device enabled the management of energy flow between the photovoltaic panel, the battery and the incubator, ensuring a stable and secure supply.

An Epcom Power Line sealed deep cycle battery, model PL-110B-12, with a capacity of 110 Ah at 12 V DC, was used for energy storage. This component provided the energy autonomy required during periods without solar radiation, ensuring the continuity of the incubation process for up to 48 hours.

Box 3

Figure 3
SolNido solar incubator prototype
Source: Own Elaboration.

The incubation system was implemented using a YUNJAS automatic incubator, with a nominal power of 35 W and the capacity to operate on alternating current (110 VAC, 50–60 Hz) and direct current (12 VDC). The incubator is equipped with an LED panel that allows for the configuration and monitoring of temperature and humidity, as well as a backup system that automatically switches from the mains (110 VAC) to battery power (12 VDC) in the event of power outages, ensuring.

Box 4

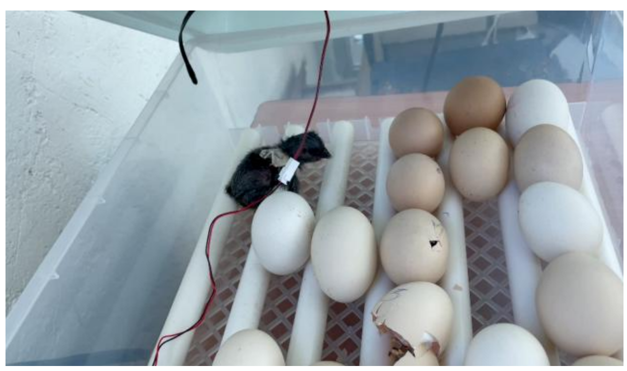

Figure 4
SolNido solar incubator prototype undergoing field testing at the Technological University of San Juan del Río
Source: Own Work

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4. Results

The prototype maintained an average temperature of 37.5 ± 0.5 °C and relative humidity in the range of 50–55%, conditions that remained stable throughout the incubation cycle and confirm the adequate performance of the control system. To maintain humidity, it was necessary to manually add approximately two litres of water to the incubator's reservoir every three or four days, as the prototype did not have an automatic supply system.

The hatch rate was 20%, a result conditioned by the nature of the eggs used, as they were provided without fertility certification. It is important to note that there was no certainty that all the eggs had been fertilised by a rooster; that is, some may have been fertile eggs, while others were probably only unfertilised laying eggs. In this context, it is projected that the system could achieve hatch rates of over 70% when using selected and verified fertile batches.

Likewise, the prototype recorded a 95% reduction in dependence on the electrical grid, as it was powered most of the time by direct current voltage from a solar-charged battery. This operating scheme resulted in an estimated environmental benefit of 0.14 tonnes of CO_2 avoided per year, directly contributing to the mitigation of emissions associated with the use of conventional electricity.

Box 5

Figure 5
Chicks hatched during the experimental phase of the SolNido prototype
Source: Own Work

Ovoscopy is a technique used to observe the inside of an egg during the incubation process, using a light source to check fertility and embryonic development. Figure X shows an egg placed in the incubator's integrated ovoscope, where light passes through the shell and reveals its internal state. This procedure is essential for identifying fertile eggs (fertilised and developing), as well as for discarding unfertilised or unviable eggs that could affect the process if they remain in the incubator. In tests carried out with the SolNido prototype, candling confirmed that some of the eggs introduced were only unfertilised laying eggs, which largely explains the limited hatching rate of 20% recorded in this first experimental stage.

Box 6

Figure 6
Egg candling, different stages of embryonic development during testing with SolNido
Source: Own Work

5. Comparison with commercial incubators

SolNido was compared with a conventional 100-egg incubator and a commercial 500-egg incubator:

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Box 7

Table 1
Comparison between different incubators

Indicator	Conventional (100)	Commercial (500)	SunNest (20)
Monthly energy consumption	45 kWh ($270 MXN)	225 kWh ($1350)	2 kWh ($12)
Annual electricity cost	$3,240 MXN	$16,200 MXN	$144 MXN
CO_2 emissions (kg/year)	235	1,176	12
Autonomy during power cuts	0 h	0 h	48 h
Initial equipment cost	$12,000 MXN	$65,000 MXN	$6,500 MXN

The brooder box is an essential device for the initial housing of chicks after hatching, as it ensures shelter, warmth and well-being from the first day of life. It is made of corrugated cardboard and has a bed of sawdust at the bottom, which helps to keep the space dry, clean and comfortable. Heat is provided by a 60-watt Philips incandescent lamp, powered by 110 volts of alternating current, which guarantees a suitable temperature for the chicks' development. Instinctively, the chicks move closer to or further away from the lamp according to their thermal needs, thus regulating their comfort. The box is also equipped with water and feed dispensers, which cover the basic nutrition and hydration requirements during the first days of life.

Box 8

Figure 7
Corrugated cardboard brooder box with newly hatched chicks, equipped with a 60 W Philips incandescent lamp, sawdust on the bottom, and feed and water dispensers

Source: Own Elaboration

Box 9

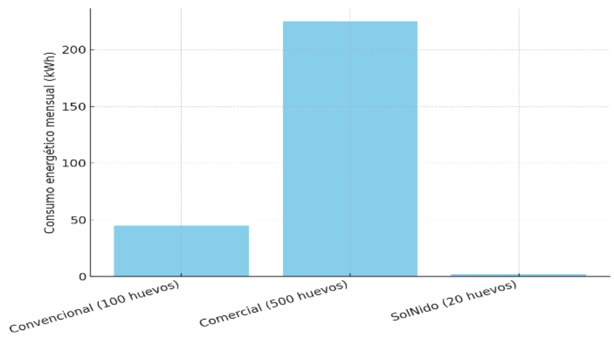

Figure 8
Comparison of annual energy consumption between a conventional incubator, a commercial incubator and the SolNido prototype. Source: own elaboration with experimental and manufacturer data, 2024

Source: Own Elaboration

Twenty-one days after hatching, the chicks show visible development in their morphology and behaviour. Their plumage has changed from an initial state of soft tufts to a denser covering, predominantly black in colour, with uniform growth on the wings, back and neck. A differentiation in the length and strength of the limbs can be observed, with well-formed legs and defined scales, allowing for greater mobility and stability. Body weight has increased significantly since birth, estimated to be in the range of 250 to 300 grams, depending on genetics and nutrition. Their behaviour reflects greater autonomy: they actively explore the brooder box, feed independently from the dispensers and display gregarious behaviour typical of the species. The breeding box is made of corrugated cardboard with a sawdust base and equipped with water and balanced feed dispensers, ensuring adequate hygiene and nutrition for this stage of growth.

Box 10

Figure 9
Chickens 21 days after hatching, showing plumage development and limb strength

Source: authors, 2024

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Figure 10 shows the Governor of the State of Querétaro, Mauricio Kuri González, accompanied by the Rector of the Technological University of San Juan del Río, Fernando Ferrusca Ortíz; the Secretary of Education, Dr Martha Elena Obregón Soto; Dr Ángel Marroquín de Jesús, professor of Renewable Energy; and Dr. Juan Manuel Olivares Ramírez, Director of the Chemistry and Renewable Energy Division, during the Citizens' Conference held on 23 July 2023 in the city of San Juan del Río, Querétaro. At this event, the SolNido project was presented as an example of technological innovation with social and productive impact.

Box 1 1

Figure 10

From left to right and in the foreground, the Governor of the State of Querétaro, Mauricio Kuri González, Rector of the Technological University of San Juan del Río, Fernando Ferrusca Ortíz, Secretary of Education, Martha Elena Obregón Soto, Ángel Marroquín de Jesús, and Juan Manuel Olivares Ramírez.

The economic and social impact of the SolNido prototype is particularly significant when analysing its projections in terms of savings, income and sustainability. At the household level, savings in electricity consumption reach approximately £2,000 per year, allowing the initial investment to be recovered in an estimated period of two years, generating net profits thereafter. Furthermore, considering a projected hatch rate of 70% with fertile eggs, each family could earn up to an additional £7,560 per year through the sale of chickens, providing a source of self-employment and productive diversification.

From a regional perspective, if the model were adopted by 100 rural families, the impact would multiply considerably: collective savings of more than £2,000 per year would be achieved, a reduction of approximately 22 tonnes of CO_2 per year and an estimated production of 8,400 chickens, directly contributing to food security and strengthening the local economy.

To put this environmental benefit into perspective, the reduction in emissions is equivalent to planting around 1,000 trees or avoiding the consumption of more than 9,000 litres of petrol in a year, which reinforces the relevance of SolNido as a sustainable solution.

These results demonstrate that SolNido is not only a technological prototype, but also a strategic tool capable of improving quality of life, generating sustainable income, and promoting more equitable and resilient rural development.

6. Discussion

The results obtained with SolNido confirm that the integration of renewable energies in poultry incubation is technically and socially viable, showing that it is possible to achieve stable temperature and humidity conditions with minimal energy consumption and high autonomy from the electricity grid.

Compared to early attempts at solar incubation based on thermal collectors (Rubio Picó, 1979; García-Hierro Navas, 2016), SolNido represents a significant advance by integrating photovoltaic energy, automatic control and electrical storage, which provides total independence from the grid.

Compared to low-cost proposals such as that of Corzo Hernández (2019), which used Arduino as a control system, this project stands out for offering a comprehensive solution that combines technological accessibility, operational reliability and environmental sustainability.

The fuzzy control system proposed by Monta Toapanta (2020) demonstrated the importance of advanced automation, although its complexity may limit replication in rural areas. In contrast, SolNido prioritises operational simplicity and scalability, making it more suitable for small and medium-sized producers who require robust but easy-to-operate systems.

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Similarly, the semi-automatic incubators developed in Ecuador (Franco Sánchez, 2022) and the sustainable production guidelines (Hernández Elizondo, 2023) find a point of convergence in this model, which ensures both productive efficiency and environmental responsibility. At the regional level, the experience of Romero Pisco et al. (2025) in Colombia reinforces the need for solar incubators as an energy resilience strategy in the face of power outages. In this context, SolNido responds to the Mexican context and has the potential for technology transfer to rural communities seeking sustainable production alternatives. Finally, the path towards digitalisation, proposed by Yerovi Parra (2021), opens up the possibility for future versions to incorporate remote monitoring through IoT, strengthening the traceability, control and efficiency of the process.

However, certain limitations observed in this first experimental phase should be noted. The initial hatching rate (20%) was conditioned by the lack of certainty regarding the fertility of the eggs used, as they were provided without prior certification or verification. As a result, both potentially fertilised eggs and unfertilised laying eggs were incubated, which reduced the success rate. Furthermore, the prototype depends on seasonal solar availability and still requires additional scalability testing, as its current capacity is limited. Overcoming these limitations will involve the use of verified batches of fertile eggs, the incorporation of automatic humidification systems, and the development of higher-capacity models that consolidate the productive and social impact of the proposal.

7. Conclusions

The development of the SolNido prototype confirms the technical feasibility of using photovoltaic solar energy in poultry incubation processes, demonstrating that it is possible to maintain stable temperature (37.5 ± 0.5 °C) and relative humidity (50–55%) conditions with a reduction of more than 90% in energy costs compared to conventional incubators. This performance validates the potential of integrating clean and accessible technologies into a strategic sector such as poultry farming, contributing directly to the reduction of CO_2 emissions and the strengthening of agricultural sustainability in rural and peri-urban contexts.

The results obtained in this experimental phase, although preliminary, show a hatching rate of 20% with non-certified eggs, which was conditioned by the lack of certainty regarding the fertility of the eggs used. However, it is projected that, by using verified fertile batches, the system could achieve hatch rates of over 70%, confirming its potential for scaling up to versions with a capacity of 200 to 500 eggs, while maintaining the principle of autonomous and sustainable operation.

Beyond its technical achievements, SolNido should be understood as an innovative proposal with high social impact, capable of improving the quality of life of families through the generation of self-employment, productive diversification, and the strengthening of food security. Its implementation opens up the possibility of developing community solar farms, operating under a maquila scheme in which different producers can access controlled, homogeneous and low-cost incubation processes, promoting productive equity and local cooperation.

In short, SolNido transcends the status of an experimental prototype to establish itself as a technological vision of the future, characterised by its replicability, social relevance and contribution to the energy transition of the agricultural sector. Its eventual mass adoption could constitute a transformative strategy for poultry farming in Mexico and Latin America, by articulating energy innovation, productive efficiency and environmental responsibility as pillars of a more just, resilient and sustainable rural development model.

8. Future projections

The SolNido project has the potential to evolve into higher-capacity versions, with incubators for between 200 and 500 eggs, integrating more efficient ventilation systems and optimised heating. Likewise, the incorporation of hybrid solar energy and electricity grid schemes is planned, guaranteeing the continuity of the process even in seasons of low solar radiation. Digitisation through smart sensors and integration with IoT technologies will enable real-time remote monitoring and traceability of the process, providing greater reliability and efficiency.

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At the social level, the proposal could take the form of a community solar farm model that functions as a maquila for local producers, where eggs are incubated in controlled and homogeneous conditions at low cost. Similarly, its inclusion in rural extension programmes and government projects would strengthen food security, self-employment and the economic resilience of vulnerable communities. Finally, diversification into other species and analysis of the environmental impact throughout its life cycle will consolidate SolNido as a replicable, sustainable technology with a high social impact in Mexico and Latin America.

9. Acknowledgements

The authors would like to thank the Technological University of San Juan del Río (UTSJR) for its institutional support, the members of the renewable energy academic body who contributed to the improvement of this work with their comments, the students of the ER01SM23 group of the Renewable Energy degree programme who participated in the testing and development of the SolNido prototype, Miguel Angel Ramírez Colin, for the tests carried out, and Verónica García Huerta for providing the eggs for this study.

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