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Opinion

Transition to Sustainable Drying Technologies Toward Zero-Carbon Rubber Sheet Production

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Opinion

Drying is one of world's oldest preservation methods. But, in contemporary society, it transcends mere agricultural processing, serving as a critical factor in energy consumption, product quality, and environmental sustainability. Traditional drying methods, both in agriculture and industry, are mostly reliant on open sun drying, smoke houses, or fossil-fuel-based hot air systems. These methods are energy-intensive, environmentally unsustainable, and increasingly inconsistent with global climate goals. Increasing population continues to exert pressure on food and industrial supply chains, intensifying need for energy and raw materials. The dual problems of ensuring food security and addressing energy shortage underline the need for sustainable technological solutions. The United Nations Sustainable Development Goals emphasize these priorities, specifically zero hunger (SDG 2), access to reasonable and clean energy (SDG 7), sustainable consumption and production (SDG 12), and urgent climate action (SDG 13). Drying technologies, and greenhouse dryers in particular, have the unique ability to contribute to both agricultural and industrial needs, thereby directly supporting these global objectives [1].

The Case of Natural Rubber

While drying has been historically discussed in the background of agriculture, its role in industrial processing is equally crucial. Natural rubber, for instance, relies heavily on drying for sheet preparation and product quality. Thailand is the world's largest rubber producer. It processes millions of tons of raw latex annually into sheet rubber. For a long time, smoke drying or fossil-fuel-based hot air drying has remained the main practice. These methods are challenging on various fronts. Depletion of forest resources, emission of large volumes of greenhouse gases and particulate matter, and degraded air quality in local communities are the ill effects of smoke drying. Fossil-fuel-based dryers, such as LPG or diesel, are expensive to operate and considerably contribute to the carbon footprint of the rubber industry [2]. Moreover, quality inconsistency remains a challenge, as over-drying or uneven drying compromises the strength and elasticity of the final sheets [3].

Recent research, including our published study "Carbon neutral drying technologies for sustainable transformation in Thailand's rubber industry" [4], has established that sustainable drying systems can transform the sector. For example, integrating microwave drying with photovoltaic energy has the potential to reduce the drying time drastically while eliminating up to 300,000 tons of CO_2 annually in Thailand's Standard Thai Rubber (STR) industry [4]. Further studies show that the integration of the renewable energy sources with the drying systems reduced the drying time by 30 to 40% and lower the operating costs by around 15–25% compared to conventional methods. Product quality is also enhanced by reducing contamination and preserving optimal material properties such as rubber sheet elasticity. Although the case of Thailand offers a strong example of sustainable drying transformation but the analogous approaches are relevant to other key rubber-producing countries such as Indonesia, Malaysia, and India. These nations also face similar challenges in conventional rubber sheet drying, including high fossil fuel use, poor product quality, and environmental degradation, making sustainable solutions equally relevant across tropical regions. Hybrid solar–biomass systems can also lower the fossil fuel requirement while ensuring round-the-clock drying capacity. These findings demonstrated that rubber drying must be central to the global conversation on sustainable transitions.

Emerging Sustainable Drying Technologies

A new generation of sustainable drying technologies is transforming both agriculture and the rubber industry. Solar greenhouse dryers shield the products from contamination [5], enhance hygiene [6], and decrease the reliance on fuelwood, while hybrid solar–biomass dryers ensure 24-hour operation with decreased fossil fuel use. Microwave–solar drying systems further accelerate drying process, enhance uniformity, and reduce energy consumption. Specifically, when powered by renewable electricity, they help in achieving goal of zero-carbon operation. Use of phase change materials or sensible heat storage extends the drying operation beyond sunshine hours, which improves reliability across the seasons [7]. At the same time, inclusion of innovations such as IoT sensors, AI-driven scheduling [8], and smart controllers enables real-time optimization of drying parameters, dropping energy waste and conserving product quality [9]. Current progress in advanced glazing and nano-coatings has also enhanced solar transmittance while minimizing infrared losses, further improving system efficiency [10]. Further, to design a prototype for sustainable drying technology, many important aspects should be taken into consideration. Thermal efficiency should be maximized through innovative glazing and insulation to capture and hold the solar energy. Choice of material must ensure durability and compatibility with products like natural rubber. Integration of various energy sources like solar, biomass and photovoltaic to ensure dependability under varying conditions. Designs must focus on operational simplicity for small-scale use, scalability for industrial use, and minimal environmental impact by applying life-cycle assessment.

Barriers to adoption

Despite their several advantages, sustainable drying technologies face several barriers that limit widespread implementation in the rubber sector.

Operational and Technical Challenges

Scaling up greenhouse or hybrid dryers from small to industrial levels necessitates progressive engineering, larger land footprints, and dependable airflow systems. Seasonal variability in solar radiation demands auxiliary heating, increasing design complexity. Further, advanced systems that integrate photovoltaics or microwaves demand skilled manpower for operation and maintenance, which is generally not easy to get in rural areas.

Economic Barriers

High costs remain the biggest hurdle faced by the smallholder farmers. Smallholder farmers, who govern rubber production in Southeast Asia, generally lack access to affordable financing. Sophisticated components such as PCMs, nano-glazing, or microwave modules continue to be expensive and scarce in availability, limiting supply chains.

Policy and Institutional Gaps

Greenhouse dryers are associated with various policy objectives, yet they are rarely included in renewable energy subsidy programs or agricultural development schemes, specifically in the context of natural rubber sheet production. This oversight restricts the capability of rubber farmers and cooperatives to access necessary financial and technical support required to implement sustainable drying technologies. The lack of established testing procedures and certification frameworks makes it challenging for farmers to assess, compare, and trust new drying solutions, particularly those designed for rubber processing. Therefore, prospective breakthroughs remain underutilized, obstructing the transition toward zero-carbon rubber sheet manufacturing.

Pathways to Overcome Barriers

To accelerate the transition, governments should recognize sustainable drying technologies, particularly rubber sheet dryers, under various renewable energy and climate adaptation schemes. Policy support should include targeted subsidies, financing mechanisms, and incorporation into post-harvest management strategies. Public–private partnerships can assist in establishing the demonstration units, shared infrastructure, and community-based drying facilities. The capacity building through the training programs for farmers, cooperatives, and small-scale processors will upgrade the technical skills and augment confidence in new systems. Incorporating life-cycle assessment (LCA) into both research and policymaking will provide credible data on environmental and economic benefits. Finally, local manufacturing of affordable dryers customized to regional conditions will cut the costs, fortify supply chains, and ensure widespread adoption of the technology.

Final Opinion

Sustainable drying is no longer an abstract concept. It is essential for both food systems and industrial resilience. In reference to natural rubber, transitioning to carbon-neutral drying systems offers numerous benefits such as reduced emissions, enhanced product quality, lower operational costs, and higher competitiveness in global markets. The transition toward zero-carbon rubber sheet production is not just a technical challenge but a moral commitment. Every ton of rubber dried sustainably contributes to climate action, reinforces rural livelihoods, and aligns with the Sustainable Development Goals. Thailand and other rubber-producing countries may lead the global shift by executing supportive policies, making targeted investments, and engaging their communities. By adapting sustainable drying technologies now, we can pave the path for a food-secure, energy-efficient, and low-carbon future. In which the humble rubber sheet becomes a symbol of innovation and sustainability.

Keywords

Zero-carbon drying; Natural rubber processing; Greenhouse dryer; Sustainable technologies; Post-harvest management

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Conflict of interest

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