Solar Thermoelectric Autonomous Drip Irrigation Using Industrial By-Product Carbon Ink for Sustainable Farming (STEP-Dripp-AI)

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In arid climates, they face extreme temperatures, water scarcity, and high energy demands for irrigation. At the same time, the aluminum industry generates carbon-rich waste, creating environmental challenges. This study presents STEP-Drip-AI (Solar Thermoelectric Autonomous Drip Irrigation), a self-sustaining system integrating solar-thermal energy harvesting, waste-derived conductive carbon paint, and automated irrigation based on soil moisture. Carbon-rich by-products were processed into conductive paint through drying, grinding, sieving, and polymer-assisted dispersion. The paint was applied to thermoelectric (Peltier) modules to reduce electrical resistance and enhance charge transport. Passive cooling using coolant-infused silicon capsules increased the temperature gradient, improving performance. The system powered an Arduino-based irrigation unit equipped with soil moisture and rain sensors, enabling demand-driven drip irrigation. Results showed a 91% increase in voltage output (0.68 V to 1.30 V) with carbon ink and a 59% improvement with cooling. Voltage output showed a linear relationship with temperature difference (~0.045 V/°C), confirming stable thermoelectric behavior. Soil moisture increased from 18% to 65% within 25 minutes using controlled drip irrigation, achieving nearly 60% water savings compared to conventional methods. STEP-Drip-AI demonstrates a scalable, energy-efficient solution that combines waste material reuse, renewable energy, and precision irrigation for sustainable agriculture in arid environments.

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