Energy-efficient greenhouse production for emission-free food cultivation

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Michel J. Verheul discusses the advancements in energy-efficient and emission-free greenhouse production in Norway, focusing on the innovative methods developed by researchers at the Norwegian Institute of Bioeconomy Research (NIBIO)

As the world faces the dual challenges of climate change and food security, the need for sustainable, year-round food production has never been greater. In Norway, where only about 3% of land is arable and the climate restricts traditional agriculture, greenhouses offer a promising solution. However, conventional greenhouse production is energy-intensive and often reliant on fossil fuels, leading to significant CO_2 emissions. A new wave of innovation – pioneered by Norwegian researchers and industry partners – aims to change this, making emission-free, energy-efficient greenhouse production both possible and profitable.

The Norwegian model: Harnessing nature and technology

Norway's unique advantages – abundant renewable hydroelectric energy, mild coastal climates, and advanced horticultural expertise – set the stage for a new era in greenhouse cultivation. At NIBIO Særheim, researchers have developed a closed, CO_2-neutral greenhouse system that grows tomatoes and cucumbers with zero emissions. The system uses solar energy for heating, LED lighting for optimal plant growth, and advanced climate control to maintain ideal conditions year-round.

A key innovation is the use of Direct Air Capture (DAC) technology, developed by GreenCap Solutions AS, which extracts CO_2 from the outside air and injects it into the greenhouse. This maintains an internal CO_2 concentration up to three times higher than ambient levels, dramatically boosting plant growth and yield. Any CO_2 that escapes is offset by additional capture, ensuring true climate neutrality.

Five steps to emission-free production

The transformation to emission-free greenhouse production can be summarized in five key steps:

Supplemental lighting:

The use of supplemental lighting allows for year-round production in Norway tripling yields from 40 to 120kg of tomatoes per square meter annually, while cutting energy use and CO_2 emissions per kilo by 40% and 68%, respectively. Switching from traditional High-

Pressure Sodium (HPS) lamps to energy-efficient LED lighting increases photosynthetic efficiency and reduces energy use by up to 40%.

Heat pumps and energy recovery:

Replacing gas boilers with electric heat pumps reduces heating energy needs by 55% and CO_2 emissions by 79%. Heat exchangers and buffer tanks store excess heat from sunny days for use at night, minimizing energy loss.

Closed greenhouse systems:

By keeping windows closed and using advanced climate control, heat, humidity, and CO_2 are retained. This not only saves energy but also allows for higher, more stable CO_2 concentrations, further increasing yields and improving fruit quality.

Direct air capture of CO_2:

DAC technology enables greenhouses to operate independently of fossil fuels, capturing CO_2directly from the air. This eliminates the need for gas combustion and industrial CO_2 supply, making the system truly emission-free.

Smart farming and optimization:

Integrating sensors, climate models, and decision-support systems enables precise control of light, temperature, humidity, and CO_2. This ‘smart farming’ approach maximizes yield and quality while minimizing resource use and environmental impact.

Results: Higher yields, lower emissions

Field trials at NIBIO Særheim have demonstrated remarkable results. Tomato yields increased by up to 40% in closed greenhouses using the Environmental Control System (ECS) and DAC, compared to traditional year-round production systems. Water use dropped by up to 90%, and the need for chemical pesticides was virtually eliminated due to the controlled environment. Most impressively, CO_2 emissions per kilo of tomatoes dropped from 4kg in traditional systems to nearly zero in the new setup.

Economic, environmental and social sustainability

While the technology is still more expensive than conventional methods – mainly due to high investment and operational costs – ongoing research aims to improve profitability by increasing production volume, enhancing quality, and further reducing energy consumption. Economic models are being developed to help growers and policymakers assess the return on investment and societal benefits of emission-free greenhouse production.

Environmental and social sustainability are also key focuses, with life cycle assessments (LCA) and social LCA used to evaluate the impacts on workers, communities, and the broader food system. The goal is to create a production model that is not only environmentally and economically sustainable but also socially responsible.

Global impact and future prospects

The Norwegian model demonstrates that it is possible to produce high-quality, emission-free food year-round – even in challenging climates. As the technology matures and becomes more cost-effective, it holds promise for adoption worldwide, helping to reduce the carbon footprint of food production and increase food security in temperate regions and beyond.

Energy-efficient, emission-free greenhouse production is no longer a distant dream. Through innovative use of renewable energy, advanced climate control, and CO_2 capture, Norwegian researchers and industry partners are paving the way for a sustainable food future. With continued investment and collaboration, this model could transform agriculture, delivering healthy, climate-neutral food to tables around the world.

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