Leiden-Delft-Erasmus Universities

The future of energy in the horticulture sector

Thesis Labs 2024-2025

3-7-2025

Universiteit Leiden The Netherlands

TU Delft

Erasmus University Rotterdam

Session Overview

- Welcome
- Introduction to the session by Yashar
- Exploratory framework explained by Friso & Emir
- Student presentations in paired segments
- Wrap-up by Yashar and Jan
- Drinks and networking

Energy Transition and the Future of Horticulture

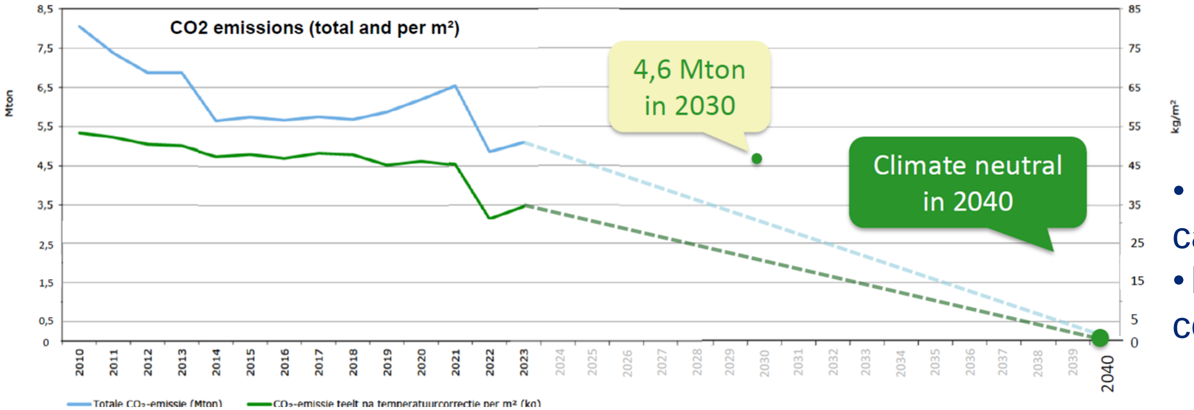
Yashar Ghiassi-Farrokhfal

About me

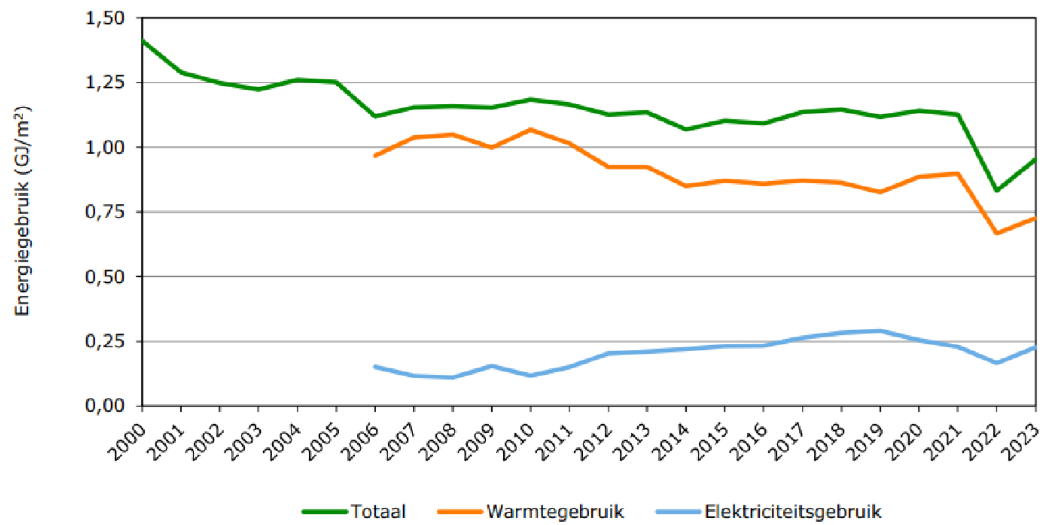
- PhD in Electrical and Computer Eng. from University of Toronto, Canada
- Associate Professor of Business Information Management
- Academic Director of the Smart and Sustainable Energy at Erasmus Center for Data Analytics (ECDA)
- Scientific lead of AI-Energy convergence (EUR/TUDelft)

Decarbonizing HC

To become carbon neutral in 2040.

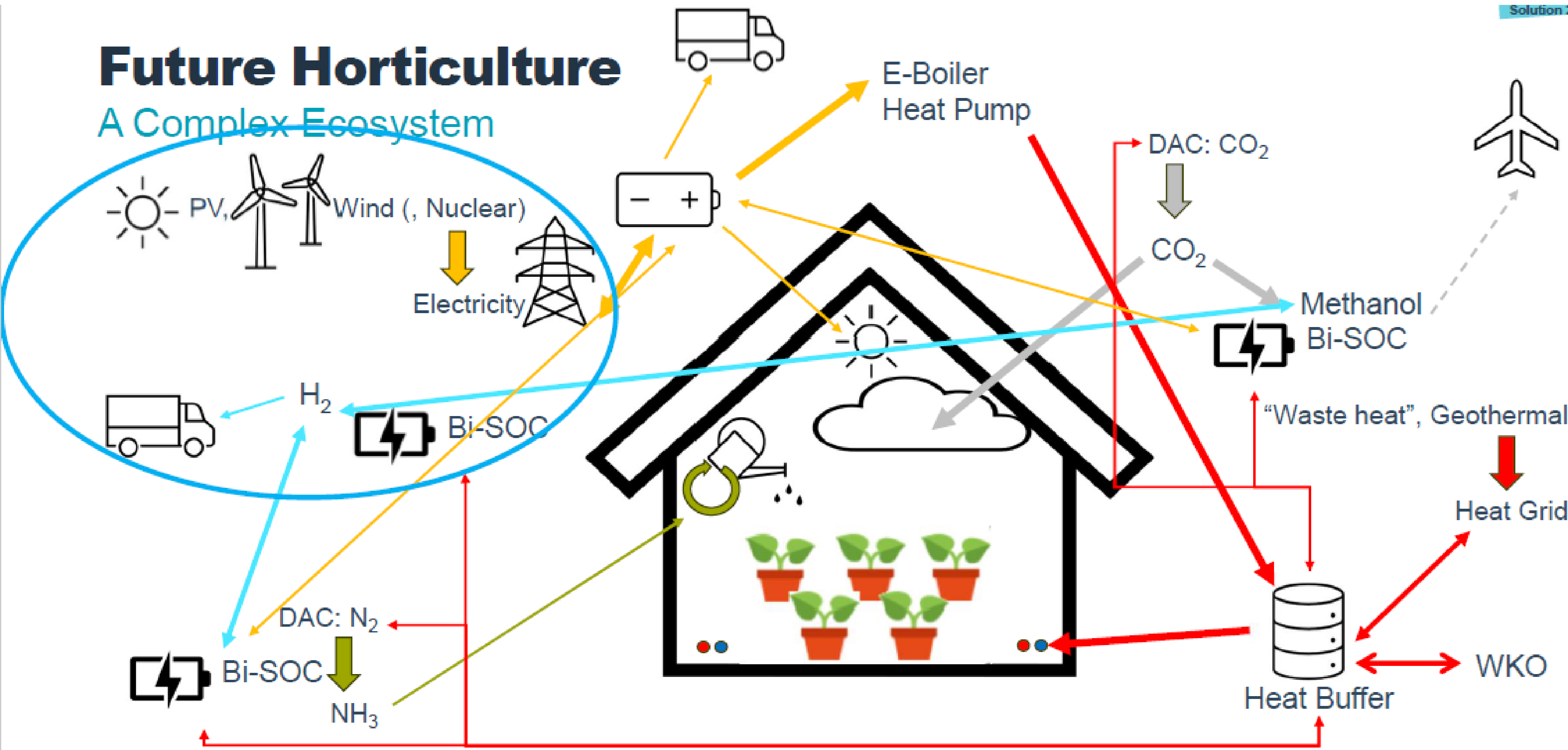


- In 2019, over 30% of NL heat demand came from the HC sector.
- HC sector used 9% of NL's total gas consumption.



Source: Slides by Liesanne Wieleman

HC: Becoming More Complex



Source: Slides by Ruben van Duren

Solutions

Demand-side solutions:

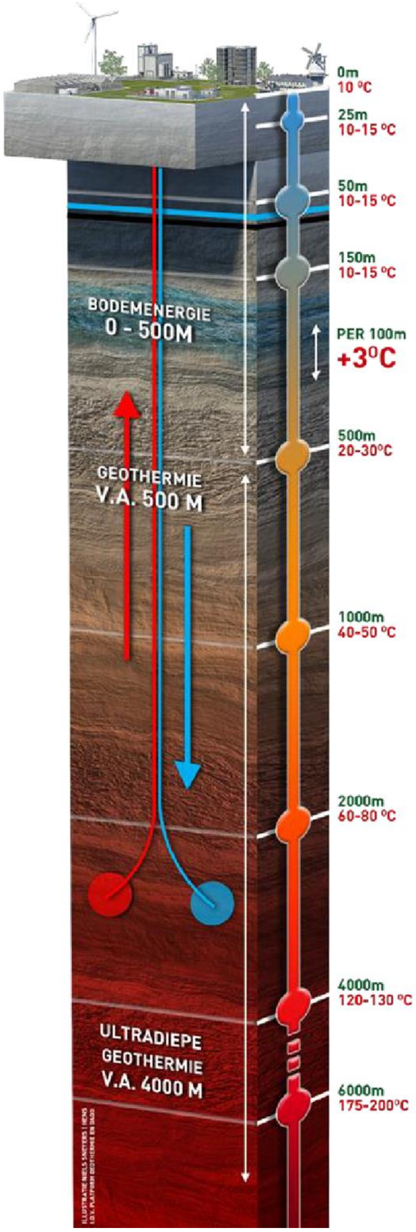
- Insolation
- Demand management (digitalization)
- Efficiency (lighting improvements)

Supply-side solutions:

- Decommission CHPs
- Geothermal
- Solar PV
- Solar thermal
- Wind
- Bio-fuel/mass

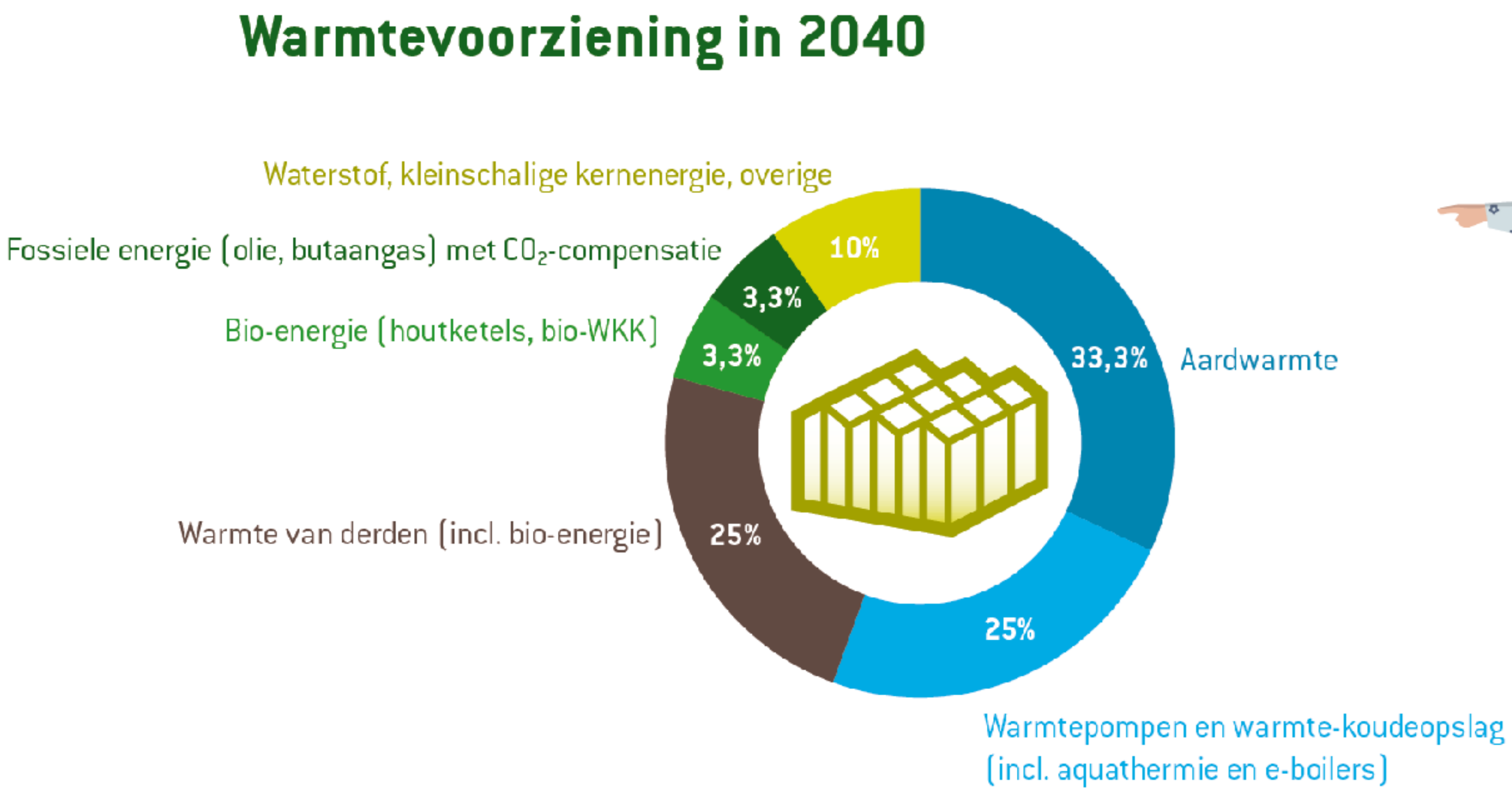
Storage solutions:

- Batteries
- Hydrogen
- Heat storage
- Heat pumps
- Carbon capture and storage



Source: Slides by Ing. Edwin Rijpsma

Example of Energy Source Predictions



Source: Slides by Liesanne Wieleman

Challenges

Energy security:

- Replacing CHPs with renewables endangers energy security.
- There is a need for optimal strategic decisions on future renewable energy sources and storage.

Economic

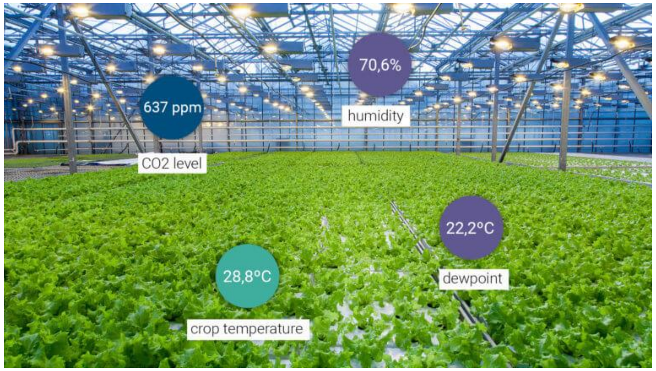
- CHPs are great source on income.
- Handling renewable variability could be costly.
- New investments on renewables and digitalization is also costly.

Decision making

- Important decisions need to be made under extreme uncertainty.
- Uncertainty due to: demand evolution, supply availability, future prices, regulatory/subsidy perspectives, etc.

Opportunity 1: Digitalization

- Improving strategic DSS
- Improving the yield
- Improving climate control
- Reducing energy consumption
- Improving lighting efficiency
- Improving the economical side



Opportunities 2: Hydrogen

Hydrogen property	Why a good fit for HC
Great seasonal storage	Seasonal heat demand
Needs high investment costs	Through energy communities the cost can be shared
Good source for heat demand	Most energy demand is heat demand
Good when multiple sectors/carriers are involved	HC is in the center of multiple sectors and carriers

Opportunity 3: Future Flex Provider

- Flexibility in power sector will be in high demand and high values.
- HC can build its future energy portfolio (with all its diversity) to be a great flex provider.
- Some HCs might also be in areas where the grid is still not congested and there is a chance for grid upgrades.

Sharing is The Key

- Sharing costs □ Huge investment. Small HCs cannot afford it.
- Sharing knowledge □ Different HCs might have different expertise and knowledge.
- Sharing data □ Better decision. HCs can help each other models by sharing date.
- Sharing risks □ HCs can hedge against risky decisions through different risk sharing instruments.

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Paradoxical Context

Rethinking Efficiency: How Growers Navigate the Energy Transition

1
Problem

- **How do growers navigate the paradox of balancing sustainability goals with profitability in transitioning to low-carbon energy?**

2
Paradox theory

- Contrary yet interrelated dualities that
  - coexist over time
  - make sense in isolation
  - look absurd together

3
Managing paradoxes

- Paradoxes lie latent in organizations
- Response shapes the loop
- Navigating paradoxes brings numerous benefits

Four Balancing Strategies

Green Glasses Don't Pay the Bills

"You can be as green as you want, but if it cost you too much money it will kill you."- I9.

Tomato–Tomahto: Expressions of Grower Identity

"Many colleagues say: 'You're thinking too much." I analyze a lot of things" – I2

Planting for the Future, Farming for Today

"I have to make decisions about my heating system for over ten years—that's my job" - I4

Cooperate to Compete

"If my flowers are too expensive Spain or Italy will take it over. Holland is such a little piece on the Earth." – I1

Scenario planning

2 methods:

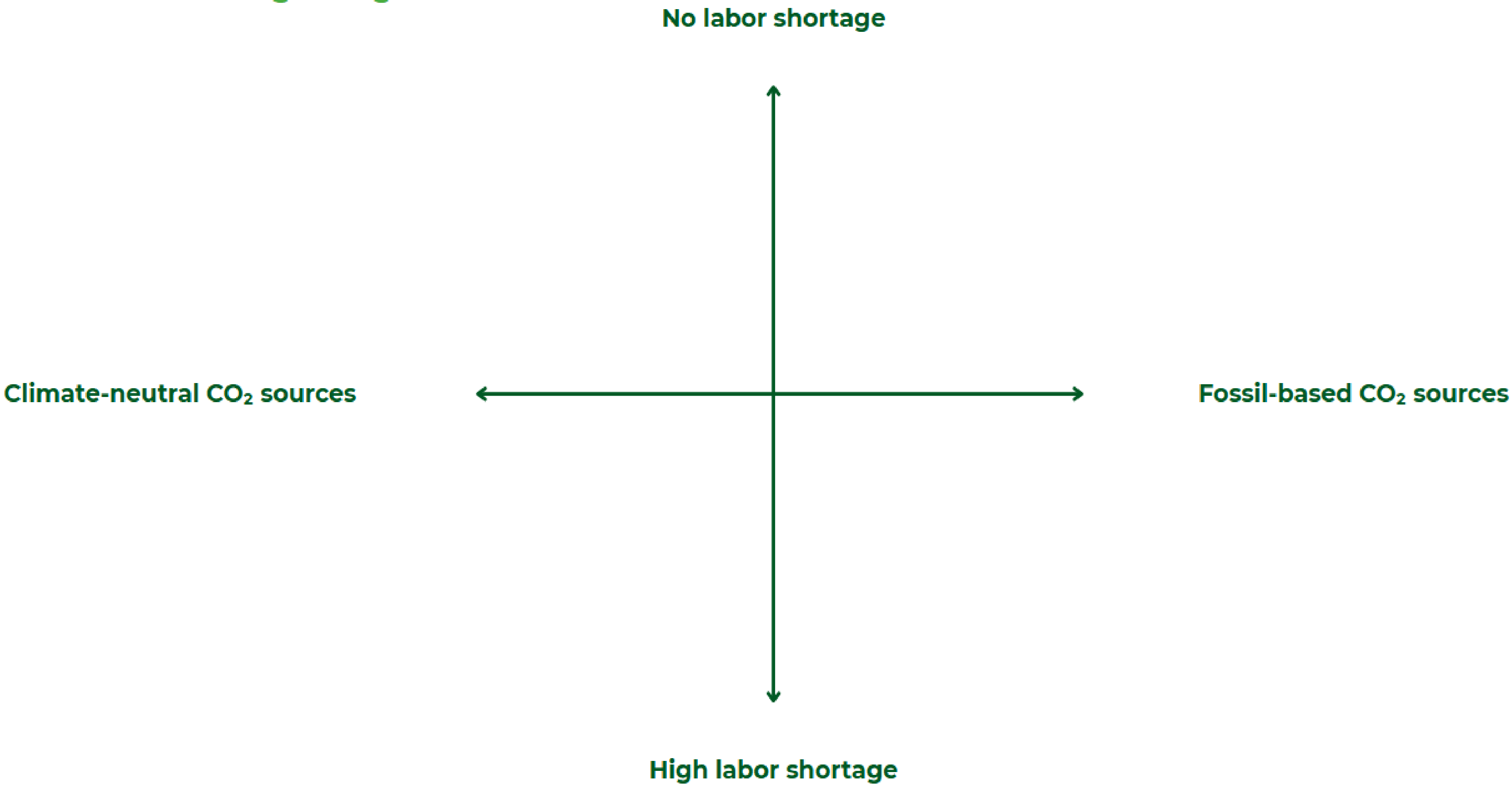
- Backcasting (goal-oriented)
- Exploratory Scenario Planning (exploratory)

Exploratory Scenario Planning (XSP):

- Exploring futures based on key uncertainties
- 2x2 matrix

Example of matrix XSP

1. Climate-neutral CO_2 sources vs. Fossil-based CO_2 sources
2. Labour shortages: high vs. no



Example of matrix XSP

1. Climate-neutral CO_2 sources vs. Fossil-based CO_2 sources
2. Labour shortages: high vs. no

No labor shortage

High-Input Optimization

Resource-Constrained Adaptation

Climate-neutral CO_2 sources ⟷ Fossil-based CO_2 sources

Technology-Driven Adjustment

Structural Reconfiguration

High labor shortage

Thesis Siu

Delphy

A Life Cycle Assessment

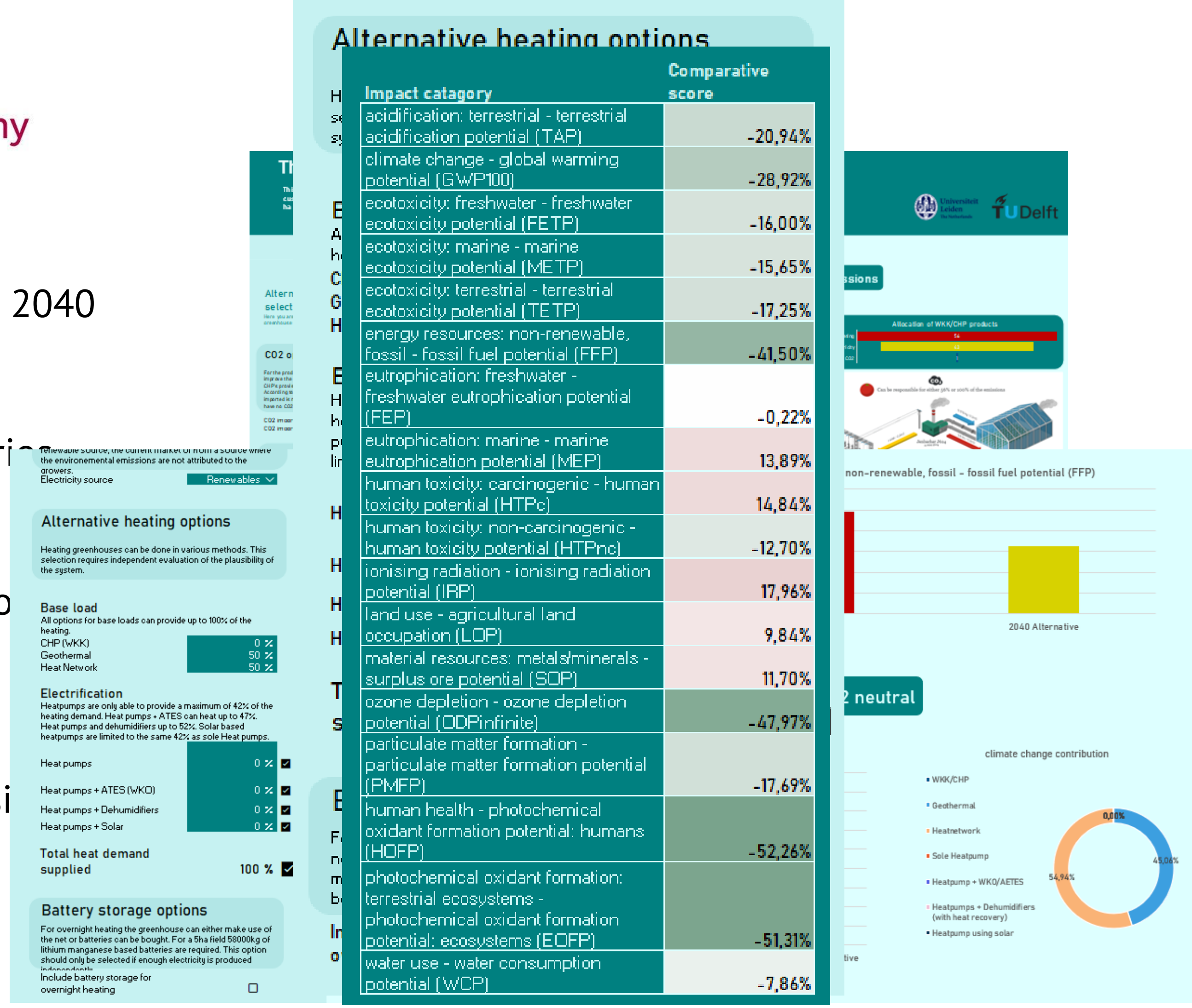
- Tomato production in 2040

What was done

- Modelling of 8 Scenari
- A test of assumptions
- An analysis of CRM's
- A decision support too

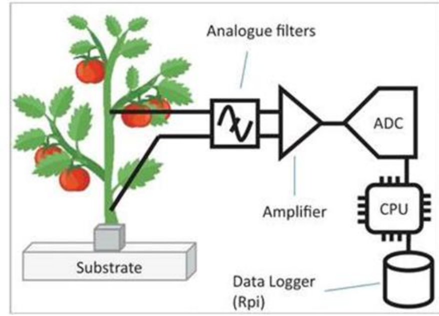
Insights

- Lack of consensus
- Lack of trade-off consi
- Lack of frugality

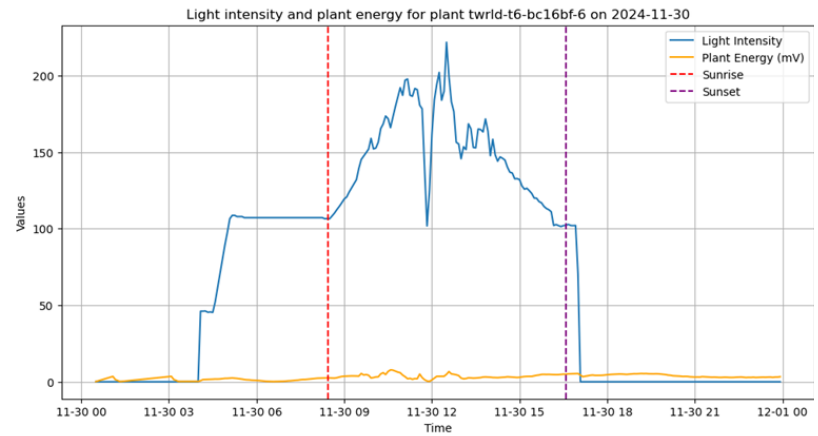


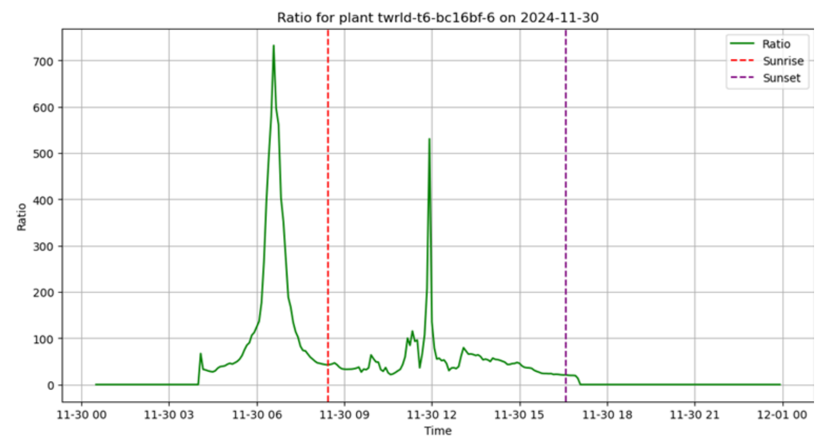
Impact catagory	Comparative score
acidification: terrestrial - terrestrial acidification potential (TAP)	-20,94%
climate change - global warming potential (GWP100)	-28,92%
ecotoxicity: freshwater - freshwater ecotoxicity potential (FETP)	-16,00%
ecotoxicity: marine - marine ecotoxicity potential (METP)	-15,65%
ecotoxicity: terrestrial - terrestrial ecotoxicity potential (TETP)	-17,25%
energy resources: non-renewable, fossil - fossil fuel potential (FFP)	-41,50%
eutrophication: freshwater - freshwater eutrophication potential (FEP)	-0,22%
eutrophication: marine - marine eutrophication potential (MEP)	13,89%
human toxicity: carcinogenic - human toxicity potential (HTPc)	14,84%
human toxicity: non-carcinogenic - human toxicity potential (HTPnc)	-12,70%
ionising radiation - ionising radiation potential (IRP)	17,96%
land use - agricultural land occupation (LOP)	9,84%
material resources: metals/minerals - surplus ore potential (SOP)	11,70%
ozone depletion - ozone depletion potential (ODPinfinite)	-47,97%
particulate matter formation - particulate matter formation potential (PMFP)	-17,69%
human health - photochemical oxidant formation potential: humans (HOFP)	-52,26%
photochemical oxidant formation: terrestrial ecosystems - photochemical oxidant formation potential: ecosystems (EOFP)	-51,31%
water use - water consumption potential (WCP)	-7,86%

Thesis Frenk



- Electrodes attached to plant stems collect bioelectrical impulses.
- Enables real-time observation of plant responses to environmental changes.
- Thesis: How AI can use biosignals to make energy-efficient LED lighting decisions
- Significant ratio spike indicates even greater mismatch between provided lighting and plant energy level.
  - LED intensity potentially excessive at that moment.
- Ai model: 6,08% energy savings





Matrix Siu & Frenk

Precision Horticulture

The Tech-Focussed Growers

The Connected Growers

Narrow Local Focus

Full Chain Impact

The Traditional Growers

The Big Picture Thinkers

Conventional Horticulture

The Traditional Growers - Conventional & Local Focus

Narrow Local Focus

Conditions:
Growers stick to familiar routines, using fixed lighting schedules and showing limited concern for chain-wide impact. Precision horticulture sensors are rarely used, and data or collaboration beyond their own business is minimal.

Implications:
They face rising energy costs, lag behind competitors, and risk exclusion from future sustainability programs. Sector innovation slows down unless support or pressure increases.

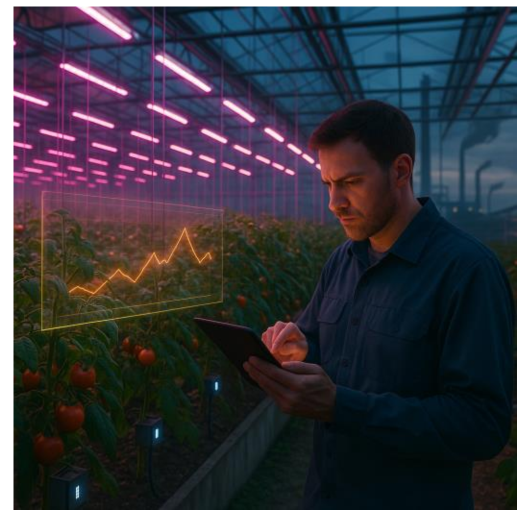
Critical Question:
What will it take to help or motivate growers who are stuck in old routines to take the first step toward innovation?

Conventional Horticulture

The Tech-Focussed Growers - Precision & Local Focus

Precision Horticulture

Conditions:
Growers prioritize real-time plant feedback through precision horticulture sensors, but often overlook the bigger picture, such as upstream CO_2 emissions or the sustainability of equipment. Decisions are typically based on local results rather than full-chain data.



Implications:
They see fast gains in lighting costs and yield, but may face criticism or certification issues for ignoring broader impact. Knowledge stays local, limiting sector-wide learning.

Critical Question:
What are the long-term risks of optimizing locally while ignoring chain-wide collaboration and standards?

Narrow Local Focus

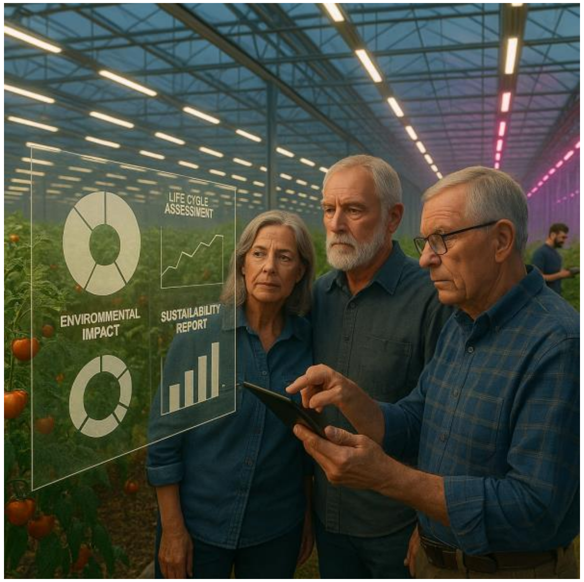
The Big Picture Thinkers - Conventional & Full Chain

Full Chain Impact

Conditions:
These growers prioritize full value chain sustainability, using lifecycle assessments to guide their decisions. However, they rely on static lighting strategies and overlook the potential of precision horticulture sensors.

Implications:
They gain credibility for environmental responsibility but miss out on daily efficiency gains. Younger or more tech-savvy growers may look for faster, smarter methods.

Critical Question:
What risks do growers face if they ignore short-term performance while pursuing long-term sustainability goals?



Conventional Horticulture

The Connected Growers - Precision & Full Chain

Precision Horticulture

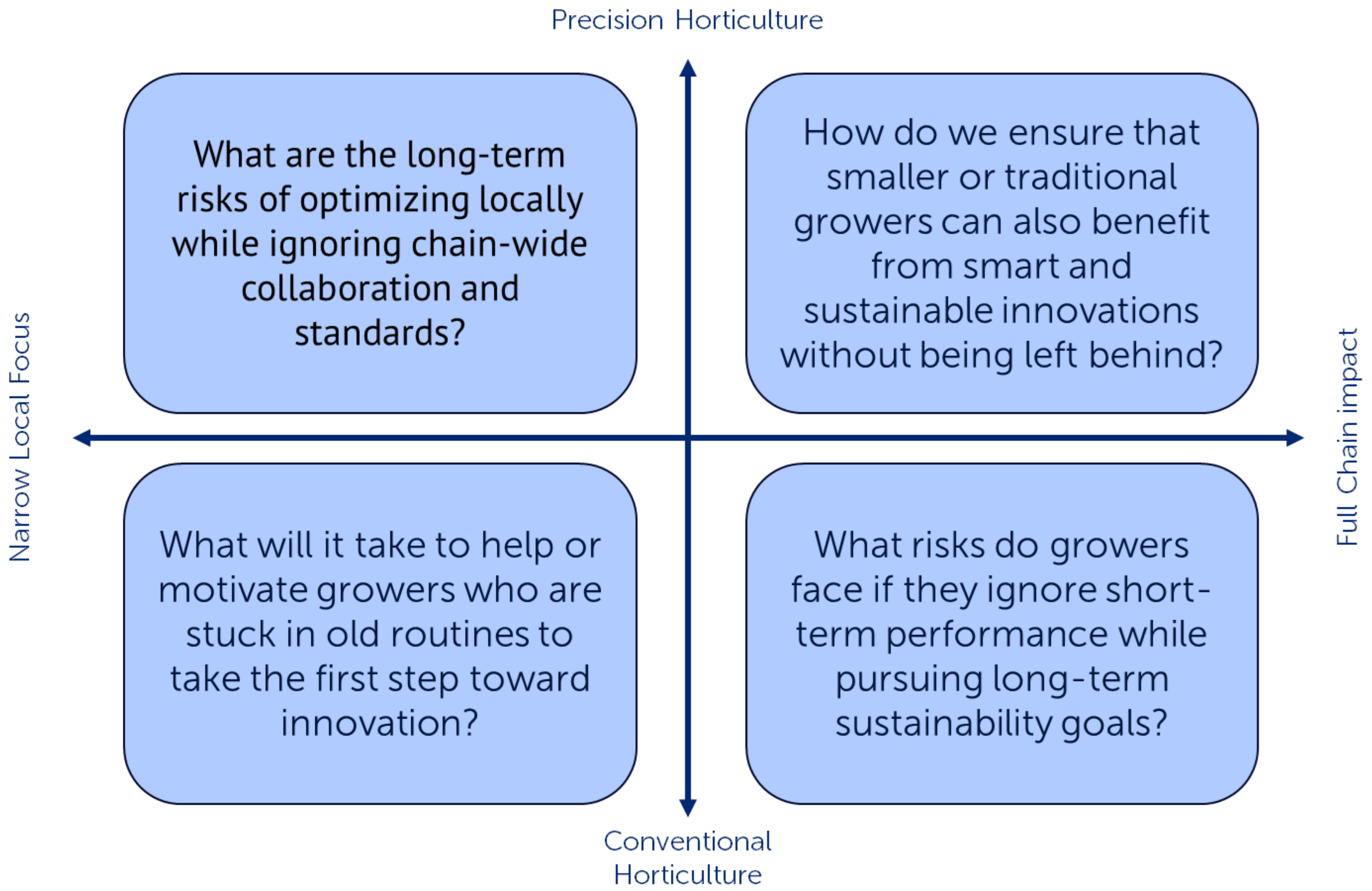
Conditions:
Growers invest in both precision horticulture sensors and a full-chain sustainability strategy. They actively share data and collaborate across the sector to align plant needs with long-term impact.

Implications:
Energy use and emissions drop significantly while maintaining high productivity. These growers set the benchmark, but others may struggle to keep up with the complexity and investment.

Critical Question:
How do we ensure that smaller or traditional growers can also benefit from smart and sustainable innovations without being left behind?

Full Chain Impact

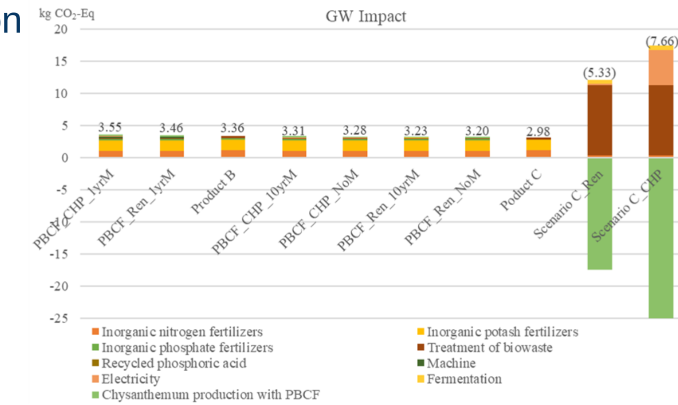
Matrix Siu & Frenk



Thesis Ye

Dutch Foundation for Innovation in Greenhouse Horticulture

From Life Cycle Assessment to Decision-Making:
Circular Fertilizer Use in Dutch Greenhouse Horticulture Decarbonization



What we did:

- An LCA comparing three fertilizer for chrysanthemum cultivation:
  - A: Plant-Based Circular Fertilizer (PBCF) from chrysanthemum residues produced by on-site decentralized system
  - B: Conventional synthetic fertilizer with market average practices
  - C: Circular phosphate fertilizer from sewage sludge
- Interviewed 11 stakeholders to explore how LCA results are interpreted and used in real decisions

Main insight:

- When scaled to the national level, PBCF implementation in chrysanthemum cultivation could reduce annual greenhouse gas emissions by **65 to over 200 tonnes CO_2-equivalent**, depending on energy configuration and machine life span

Benefits
- Soil health
- Fertigation fit
- Crop-specific NPK

Barriers
- Residue variability
- Machine cost
- Fertilizer stability

Decision Drivers
- Ease of use
- System compatibility
- Long-term stability

LCA Perception
- Too complex
- Hard to explain
- Negative CO_2 unclear

Policy & Certification
- MPS favors PBCF
- Subsidy > LCA

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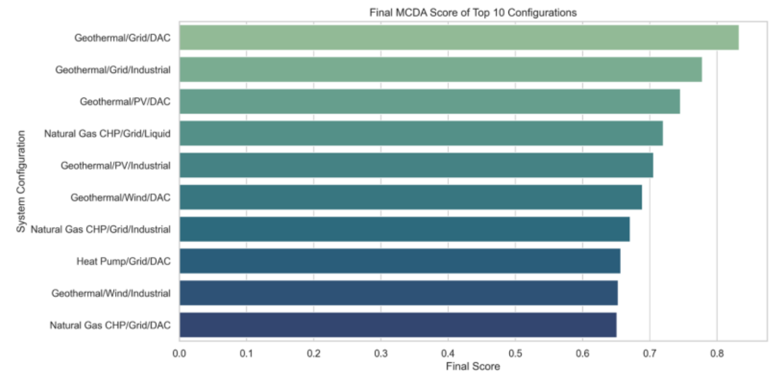
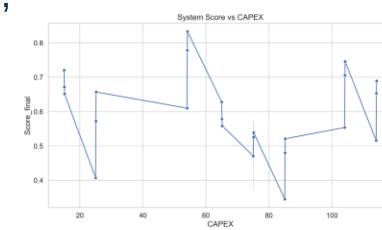
Thesis Lorenzo

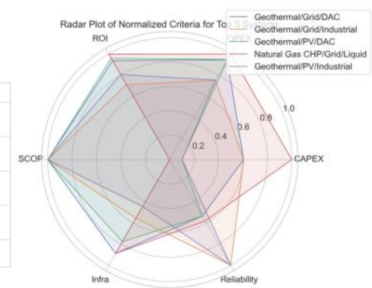


Techno-Economic Optimization of Greenhouse Energy Systems

What we did:

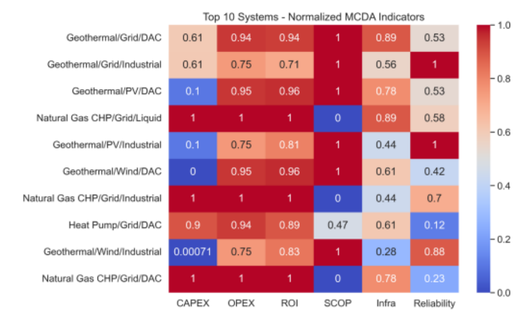
- Evaluated 27 greenhouse energy configurations integrating renewable heating (geothermal, heat pump, natural gas CHP), electricity (PV, wind, grid), and CO_2 sourcing (DAC, industrial, liquid).
- Applied a structured Multi-Criteria Decision Analysis (MCDA) framework



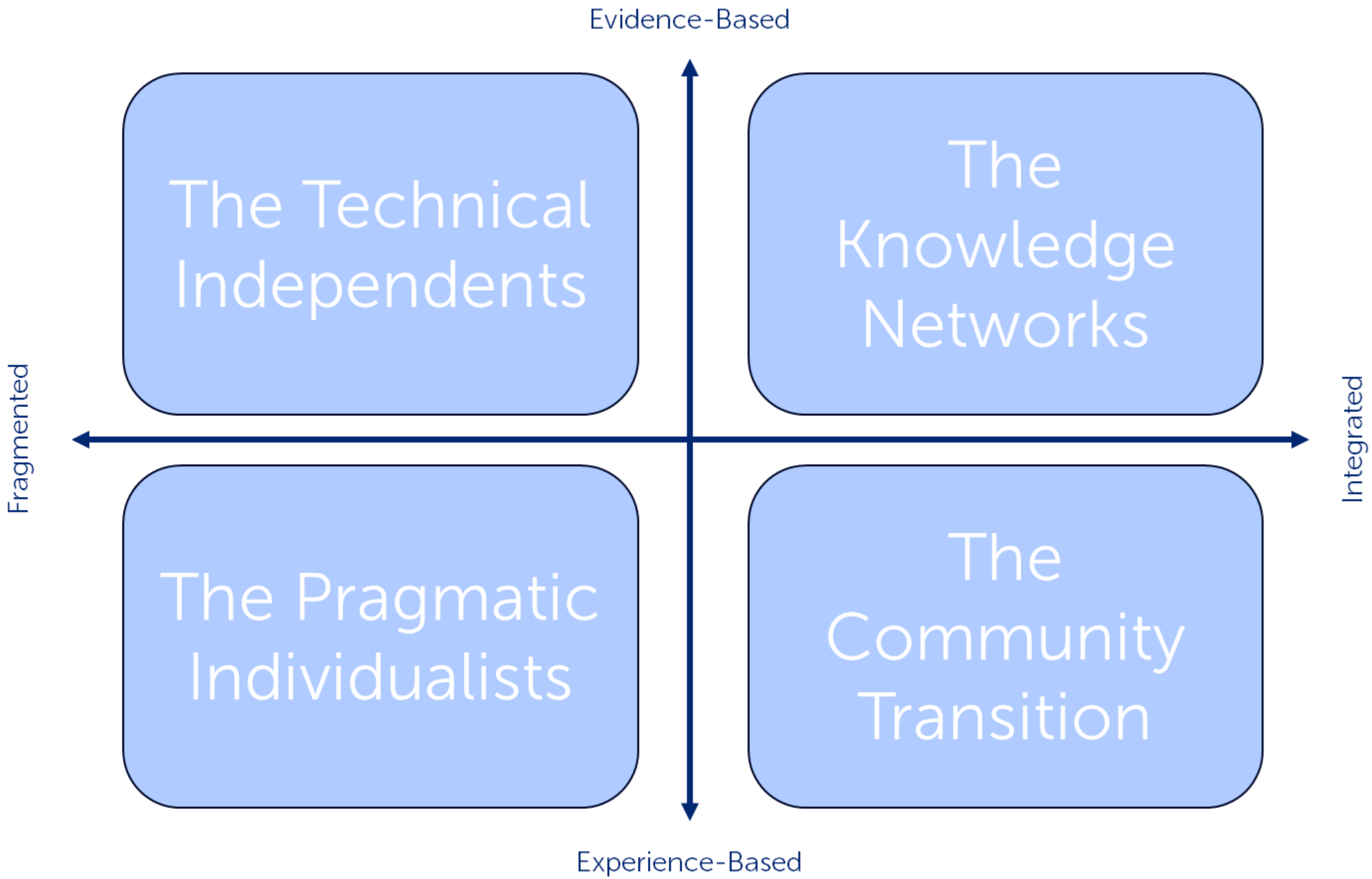


Main insight:

- Geothermal heating combined with Direct Air Capture (DAC) for CO_2 significantly outperformed conventional and alternative renewable options.
- CHP+Grid+Industrial CO2 is still really viable.



Matrix Lorenzo & Ye



The Pragmatic Individualists

Cost comes first, carbon comes last

Fragmented

Conditions:
These growers prioritize cost-efficiency and operational familiarity, sticking with fossil-based systems like **natural gas CHP/.** They make changes only when the financial case is clear, environmental metrics are secondary, and technical tools like **MCDA or LCA** are rarely used directly.

Implications:
They benefit from **low-risk, low-cost operations** in the short term, but risk missing c**ritical windows** for innovation or policy support. While they maintain economic stability, they may **fall behind** in sustainability performance and **lose competitiveness** as subsidies shift or regulations tighten.

Critical Question:
Is it rational to expect individual actors to lead the green transition when fossil-based options remain more profitable?

Experience Based

The Technical Independents

Decisions guided by technical assessments, with limited social coordination

Evidence-based

Conditions:

These growers make decisions based on **technical performance data**, adopting innovations like heat pumps, DAC systems, or low-carbon fertilizers **without waiting for peer approval**. They rely on **benchmarking, personal experimentation, or expert advice** but without coordination across the sector.

Implications:

They can be **frontrunners in decarbonization**, but their efforts remain isolated. Without shared standards or support structures, **results vary** and innovation is **hard to replicate**. Sector-wide impact is limited by the **lack of alignment**.

Critical Question:
Can technical fixes alone drive meaningful change, or do they risk ignoring the broader social and economic system?

Fragmented

The Community Transition

Decisions shaped by trust, not metrics

Integrated

Conditions:
Growers rely on peer learning and trust-based networks to guide decisions. Instead of acting on technical data alone, they adopt innovations **gradually**. Once others in their community validate its usefulness in practice. Environmental tools like LCA are viewed as supporting, but not driving action.

Implications:
Collective adoption builds over time as growers exchange **firsthand experiences**. Although this may delay decarbonization, it builds stronger legitimacy and reduces adoption risks. Over time, emissions may fall more sustainably as shared practice replaces individual skepticism.

Critical Question:
Should we tolerate higher emissions today if it helps communities make decisions for tomorrow?

Experience-based

The Knowledge Networks

Decisions shaped by collectively generated metrics

Evidence-based

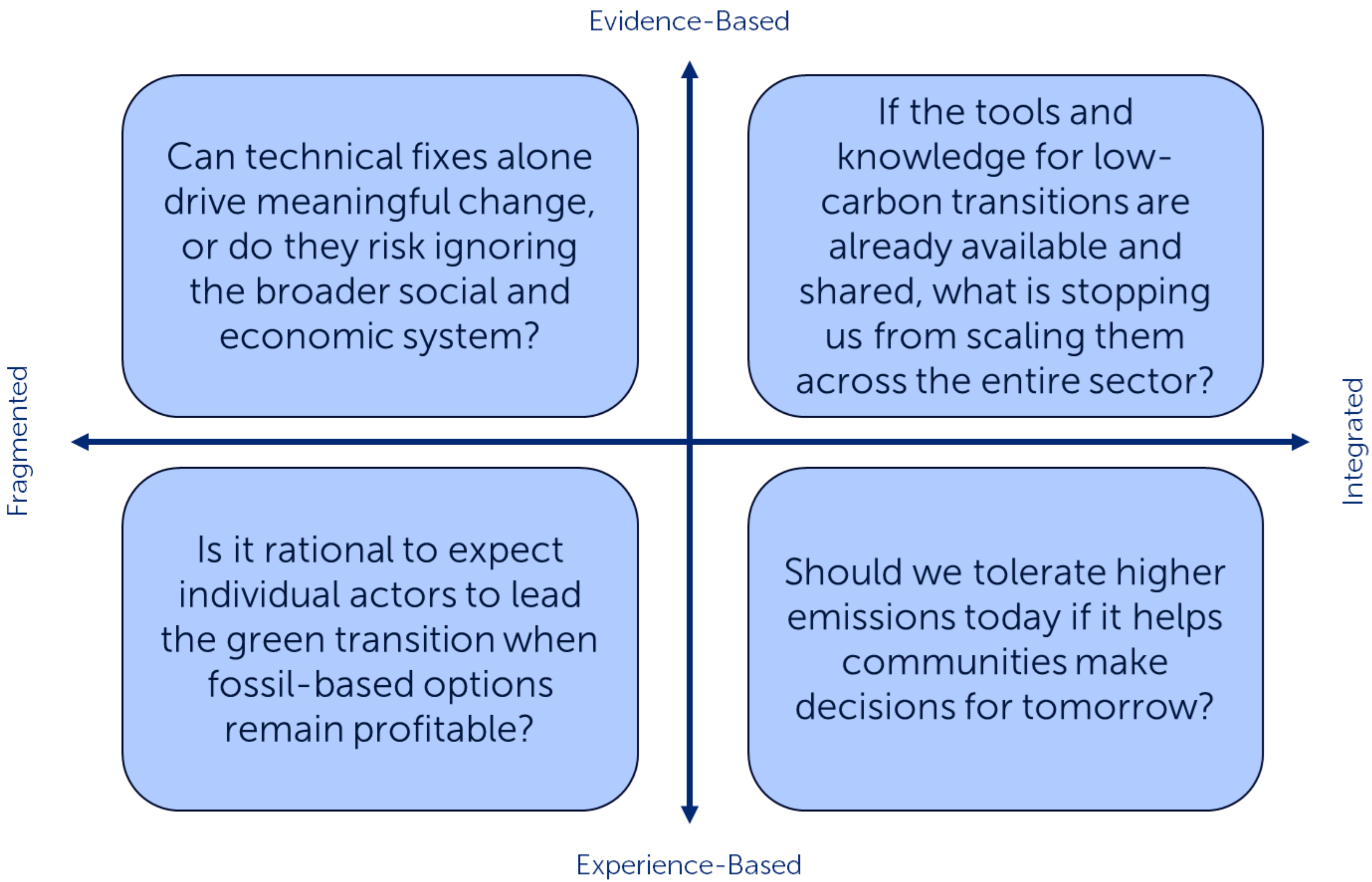
Conditions:
Growers and other stakeholders operate within shared knowledge systems (e.g. MPS calculator). Technical assessments like LCA and MCDA gain traction when **translated into practical tools and backed by institutions**. Collaborative clusters adopt shared indicators to compare, benchmark, and align strategies across the sector.

Implications:
This approach enables **scalable, coordinated decarbonization**, especially when metrics are made salient and credible for growers, can they drive broad adoption of the sustainable practices.

Critical Question:
If the tools and knowledge for low-carbon transitions are already available and shared, what is stopping us from scaling them across the entire sector?

Integrated

Discussion


Evidence-Based
Can technical fixes alone drive meaningful change, or do they risk ignoring the broader social and economic system?
If the tools and knowledge for low-carbon transitions are already available and shared, what is stopping us from scaling them across the entire sector?
Fragmented
Integrated
Is it rational to expect individual actors to lead the green transition when fossil-based options remain profitable?
Should we tolerate higher emissions today if it helps communities make decisions for tomorrow?
Experience-Based

Thesis Guido: Clear Strategic Guidance: Current LLMs Insufficient, but Scaling Provides Predictable Roadmap

LLMs on optimization problems in greenhouses

For Greenhouse Operators:

- **Stick with proven solutions:** Mathematical methods deliver 4-44% cost savings → deploy these now
- **Avoid premature LLM investment:** 31.1% error rate is unacceptable with 10-15% profit margins

For Technology Providers:

- **Avoid costly mistakes:** Research prevents investment in insufficient current technology while providing quantified roadmap for future viability
- **Scale vs. dataset trade-off:** 10x model increase likely infeasible - focus on dataset quality and agriculture-specific fine-tuning instead

Thesis Tom: Energy Decisions as a Social Process

A qualitative case study on vegetable greenhouse Horticulture

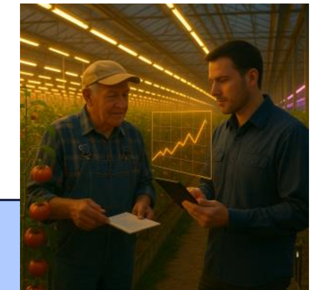
What was done

- 13 semi-structured interviews with growers, advisors & cooperative leaders and GlastuinbouwNL
- Focus on medium-sized, vegetable producers in horticulture

What was found

- Social influence en social learning play an imporant role in energy innovation adaption
- Social influence between growers is often more important than top-down advise
- Strong sector identity can foster social learning and collaboration
- **Energy seen as a shared challenge** → collaboration across competitors
- Scaling within the sector can shift learning into exclusive peer groups

Greenhouse Innovation Futures: AI Optimization meets Social Networks



High AI Precision >70%

Low Social Cohesion

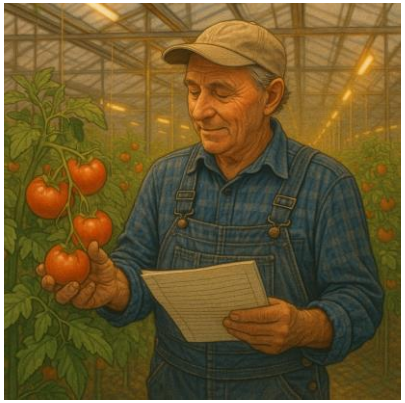
High Social Cohesion

Low AI Precision <40%

Low Social Cohesion	High Social Cohesion
The Tech Leaders	The Precision Commons
The Individual Adopters	The Learning Networks

Quadrant 1: The Individual Adopters

Low social cohesion



Conditions: Growers operate independently with current AI limitations, using <200B parameter models for LED scheduling while showing limited engagement with peer networks. Energy optimization decisions rely on individual assessment rather than collective learning or advanced AI capabilities.

Implications: Growers may face rising energy costs, lag behind competitors with better AI systems, and risk exclusion from collaborative sustainability programs.

→ Sector innovation can slow down.

Critical Question: Can AI innovation happen without social learning and collaboration within the sector?

Low AI-precision <40%

Quadrant 2: The Learning Networks

High social cohesion

Conditions: These growers prioritize peer networks and collective energy strategies, using trust-based decision making to guide LED investments. However, they rely on current AI limitations with <200B parameter models achieving only 30-40% optimization success.

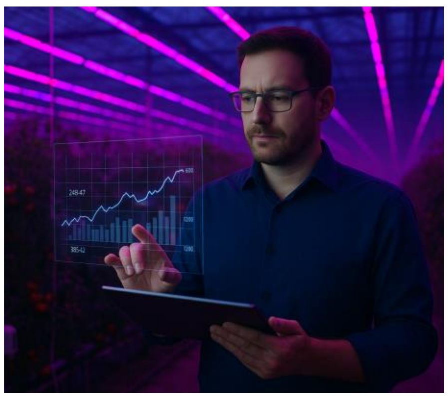
Implications: They maintain sector cohesion and collaborative culture but miss out on significant energy efficiency gains from advanced AI. The sector may fall behind international competitors who achieve better AI-driven LED optimization.

Critical Question: What risks do growers face if they maintain collaborative approaches while advanced AI-driven LED optimization capabilities remain limited, and how can collective action accelerate AI development?

Low AI-precision <40%

Quadrant 3: The Tech Leaders

High AI precision >70%



Conditions: Growers prioritize individual AI investments and LED optimization through advanced 600B+ parameter models, but operate with limited peer network engagement. AI configurations and energy management insights remain individual rather than shared through collaborative platforms.

Implications: They achieve rapid gains in LED efficiency and energy costs but may face sector fragmentation as knowledge stays isolated. The Dutch greenhouse sector's collaborative culture becomes weaker, potentially undermining collective climate goals by 2040.

Critical Question: What can larger and innovating companies gain by sharing knowledge with smaller/less innovative companies?

Low social cohesion

Quadrant 4: The Precision Commons

High AI
precision >70%

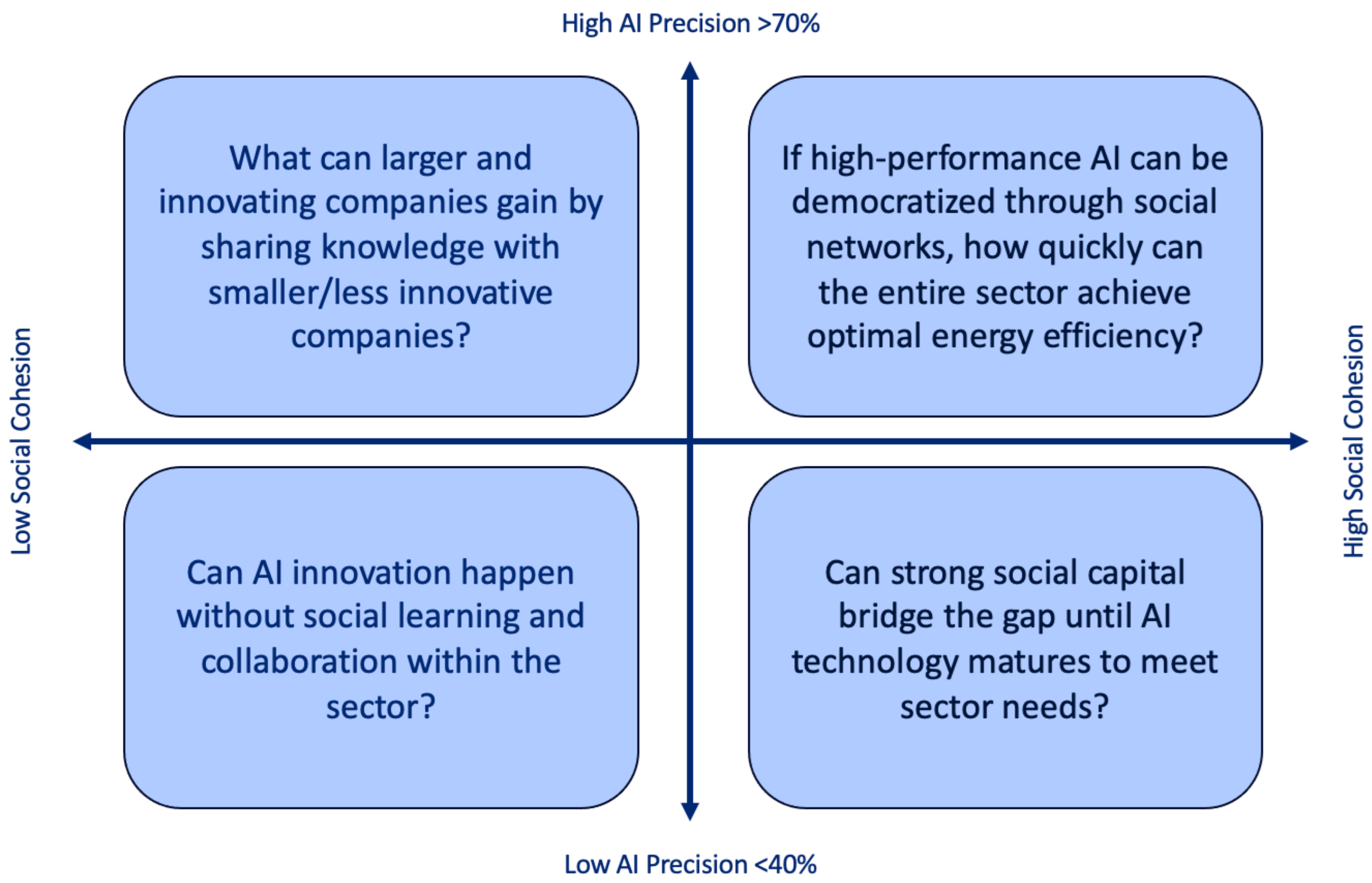
Conditions: Growers invest in both advanced AI systems (600B+ parameter models) and maintain strong peer networks through energy cooperatives. They actively share LED optimization configurations and collaborate across the sector to align AI-driven energy management with collective sustainability goals.

Implications: Energy costs and emissions drop significantly while maintaining high productivity through shared AI innovations. These growers set the benchmark for the sector, but smaller operators may struggle to keep up with the complexity and investment required for advanced AI systems.

Critical Question: How do we ensure that smaller or traditional growers can also benefit from advanced AI-driven LED optimization without being left behind when early adopters share knowledge through peer networks?

High social
cohesion

Discussion


High AI Precision >70%
What can larger and innovating companies gain by sharing knowledge with smaller/less innovative companies?
If high-performance AI can be democratized through social networks, how quickly can the entire sector achieve optimal energy efficiency?
Low Social Cohesion
High Social Cohesion
Can AI innovation happen without social learning and collaboration within the sector?
Can strong social capital bridge the gap until AI technology matures to meet sector needs?
Low AI Precision <40%