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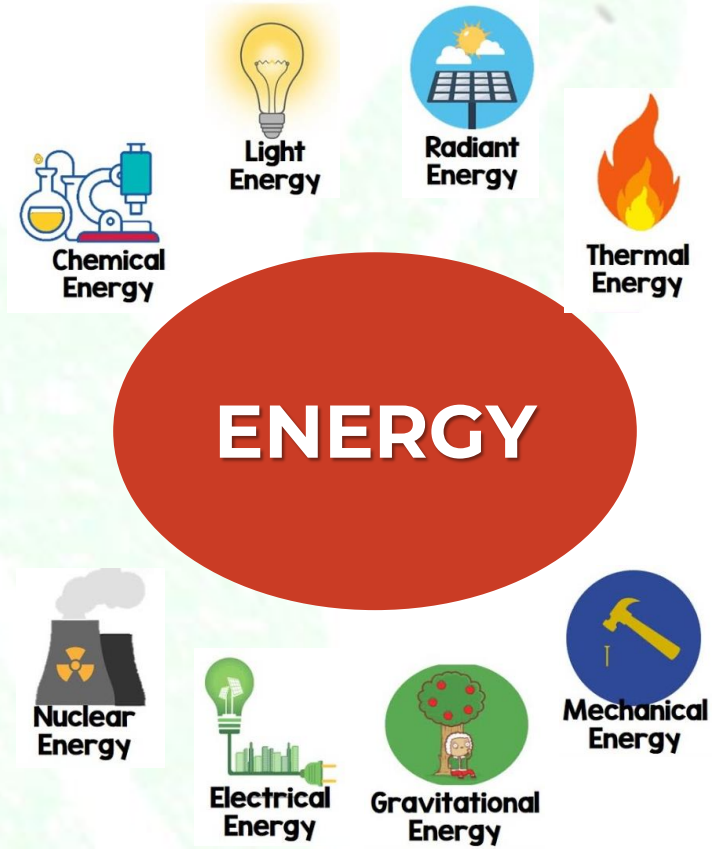
Module 5:
ENERGY

Motivation

Greenhouse

- CROPS
- CROPS PRACTICES
- EQUIPMENT AND AUTOMATION SYSTEMS



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Objectives

- Energy use
- Energy measurement
- Energy saving
- Energy efficiency

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Competencies/Skills

- Energy Management
- Equipment / sensors
- Saving measures
- Improvement measures

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Sections

5.1. The Importance of Energy Management

5.2. Energy Saving and Energy Efficiency Measures

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Module 5: ENERGY

Lesson 5.1:
Importance of energy management

SUMMARY

1. Overview of energy demand and consumption

2. Energy audits

3. Equipment used to measure energy

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1. OVERVIEW OF ENERGY DEMAND

- General introduction
- Energy use in greenhouse production
- Energy balance

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SUSTAINABLE PRODUCTION

SUSTAINABILITY

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SUSTAINABLE PRODUCTION

https://www.futurelearn.com/info/courses/sustainability-society-and-you/0/steps/4618

IN SUMMARY:

- Respect and minimize the impact on biodiversity
- Maintain soil and water health
- Reduce resources usage (water)
- Efficient resources usage

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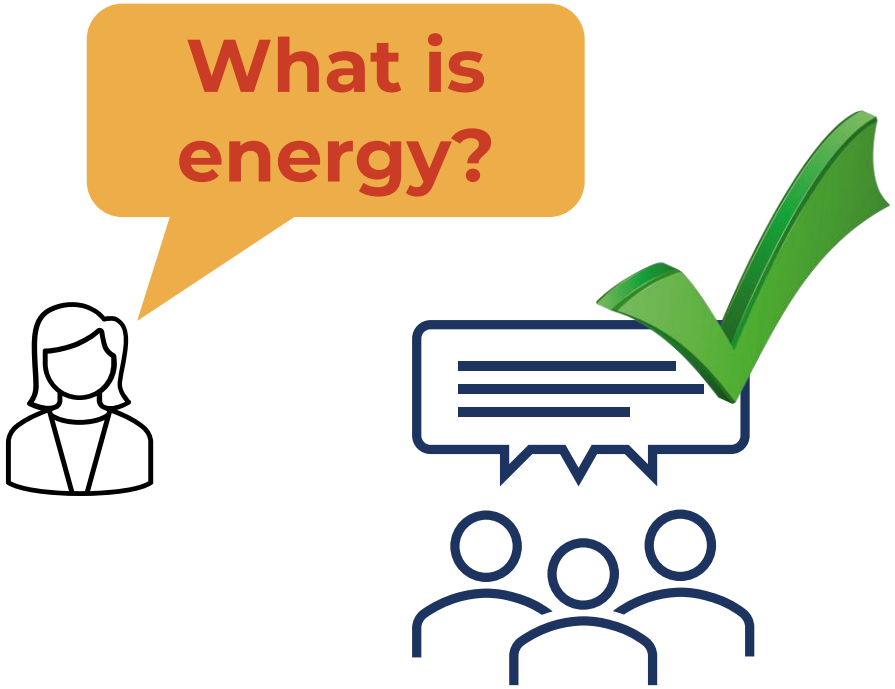
ENERGY



FORM

electrical, thermal, mechanical, radiant, kinetic, potential...

SOURCE

solar, wind, nuclear, hydropower, chemical, biomass.....

TRANSFORMED AND TRANSMITTED

PHYSICS: CAPABILITY TO DO WORK

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ENERGY SOURCES

Primary energy:

- Energy sources that are available in nature (solar, oil, natural gas, coal, hydro, wind, biomass…)

Final energy:

- Forms of energy that are directly made available to the final consumer (electricity, fuels…)

Renewable energy:

- Forms of energy from sources that are renewed (sun - PV or thermal, biomass, hydro, wind, geothermal, waves…)

ENERGY USE IN GREENHOUSE PRODUCTION

DIRECT ENERGY

INDIRECT ENERGY

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What is direct and indirect energy?

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ENERGY USE IN GREENHOUSE PRODUCTION

Direct Energy:

used directly: diesel used in machinery, energy used for climatization, lighting, irrigation systems, etc. (electricity, natural gas).


(Source:cema-agri.org/)


(Source:growertechnicalsales.com)


(Source:netafim.com/)


(Source:apholland.nl/)

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ENERGY USE IN GREENHOUSE PRODUCTION

Indirect Energy:

used for the inputs production including fertilizers, agrochemicals and auxiliary materials (thermal screens, plastic films, irrigation pipes, etc.).

(Source:hydalpoint.com/)


(Source:greenproventures.com/)


(Source:growspan.com/)

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Energy consumption variation in different tomato greenhouses

Country	Direct energy		Indirect energy		
	Diesel and electricity for irrigation	Other energy (heating, illumination)	Fertilizers	Agro-chemicals	Materials
Germany	0.0	99.7	0.3	0.0	0.0
Greece (unheated)	41.6	0.0	12	6.4	40
Greece (heated)	11.46	87.5	0.54	0.03	0.47
Portugal	68	0.0	12.0	1.0	19.0
The Netherlands	0.0	99.3	0.7	0.0	0.0

(Source: Meyer-Aurich et al, 2012)

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Greenhouse environmental control

MAIN GOALS:

- Maximise solar radiation
- Reduce heat losses (winter)
- Reduce high temperature (summer)

Level of technology

High-tech Northem — **EUROPE** — **Low-medium tech Southern**

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Greenhouse environmental control

MEDITERRANEAN

- Plastic coverd
- Natural ventilation
- Investment low-moderate
- Irregular production
- Limited yield and quality

NORTHERN EUROPE

- Glass coverd
- Sophisticated control systems
- Investment high
- Regular production
- High yield and good quality

CLIMATE CONDITIONS

Greenhouse design and technology

IMPORTANT

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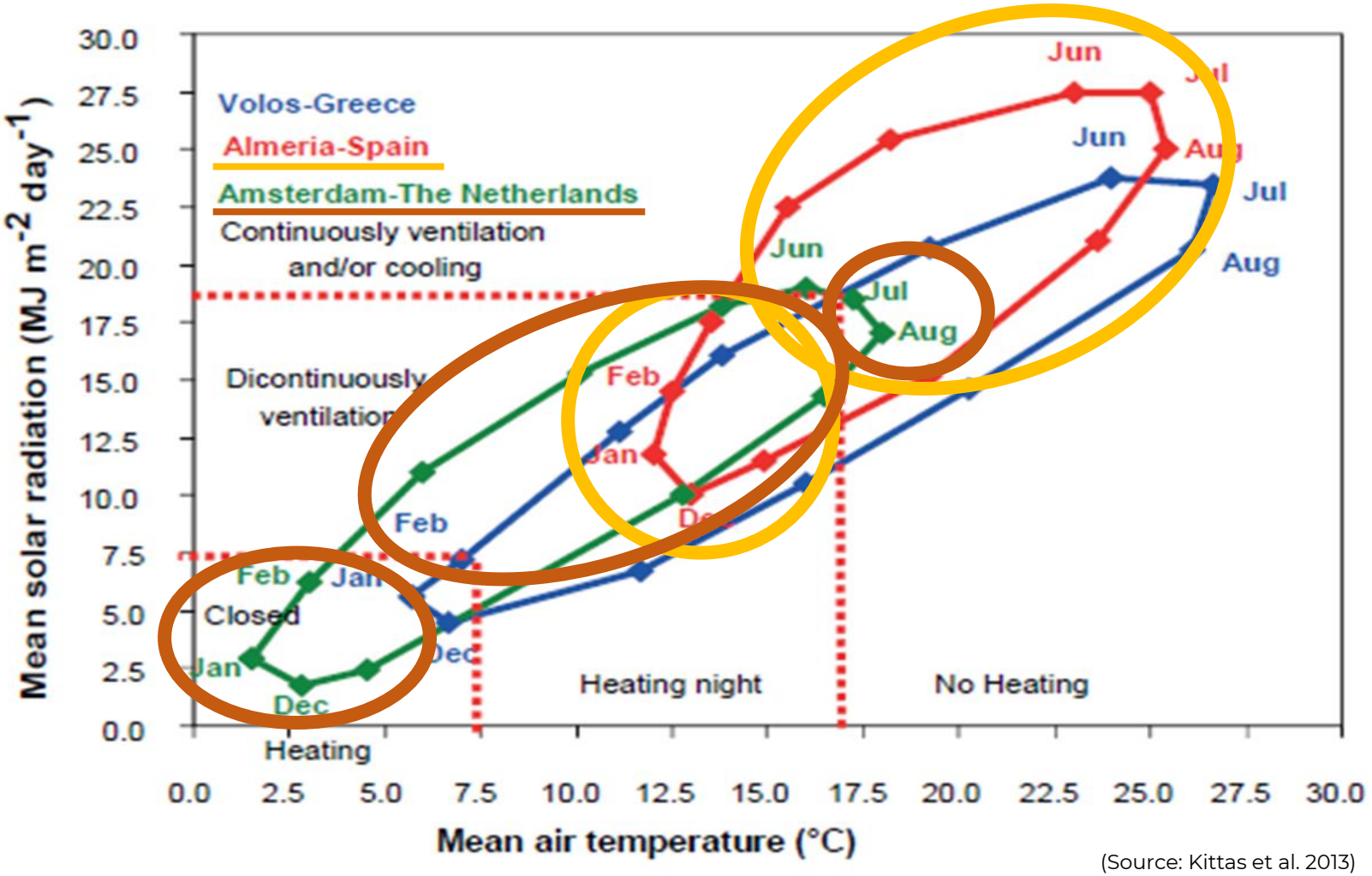
Mean solar radiation versus mean air temperature for several locations around Europe



(Source: Kittas et al. 2013)

CLIMATE CONDITIONS

Technologies

Energy consumption

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Energy consumption in tomato greenhouse production

Country	*Production (t ha^{-1})*	*Specific energy (GJ t^{-1})*	
UK	213	137	Stanhill (1980)
Spain	120	1	Muñoz et al. (2008)
	200	7	Antón et al. (2009)
	165	4	Torrellas et al. (2012)
Greece	160	1,2	Baptista et al (2014)
Portugal	180	2	Baptista et al (2014)
The Nertherlands	640	24	Baptista et al (2014)

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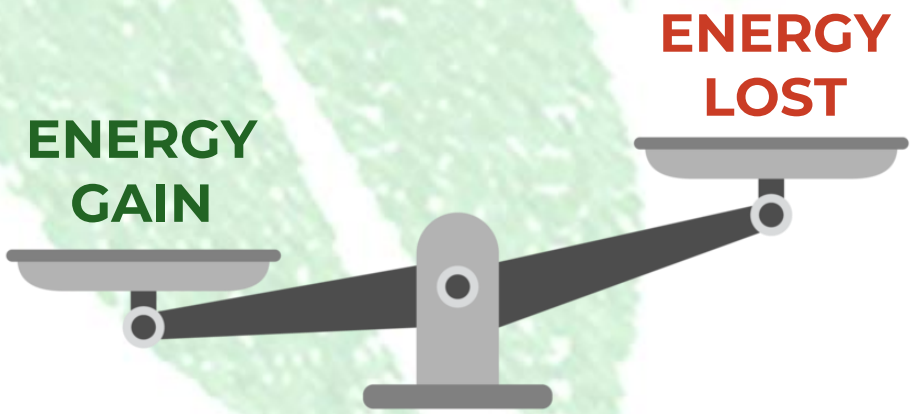
ENERGY BALANCE

Ventilation
Heating
Cooling

First Principle of Thermodynamics



GROWING CONDITIONS

Support material
Recommended references

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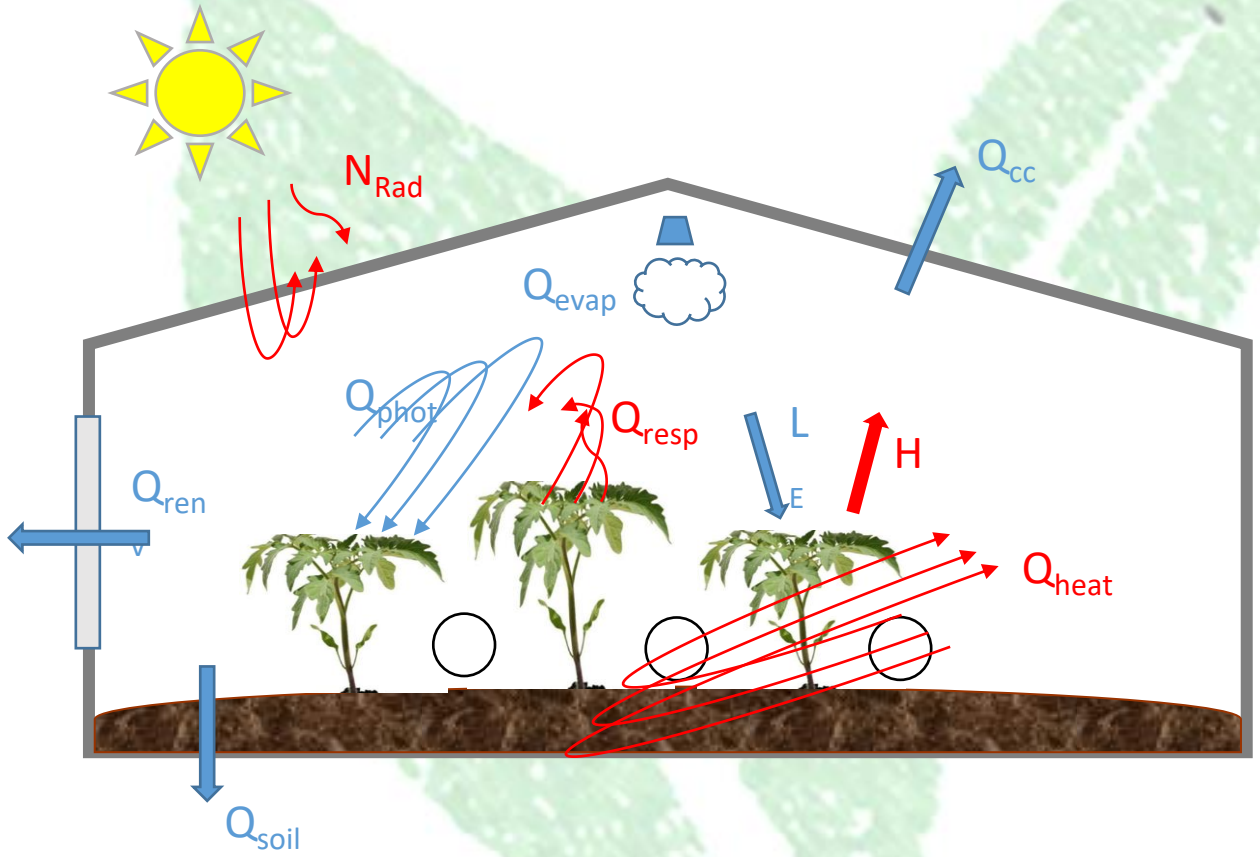
ENERGY BALANCE

G = L ➡ Equilibrium

G > L ➡ Cooling needs

G < L ➡ Heating needs



$$N_{Rad} + Q_{heat} + Q_{resp} + C_a \cdot H = C_a (Q_{cc} + Q_{renv} + L_E) + Q_{phot} + Q_{evap} + Q_{soil} \quad [W]$$

Energy gained (G) | Energy lost (L)

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COOLING DURING HOT DAYS

$$N_{rad} + Q_{heat} + Q_{resp} + C_a \cdot H = C_a (Q_{cc} + Q_{renv} + L_E) + Q_{phot} + Q_{evap} + Q_{soil} \pm Q_{store} \ [W]$$

Decrease

Whitening

Shading net + ventilation

R_{en}

Ventilation

Increase

Cooling system

Fog system + ventilation

INCREASED TEMPERATURE ON COLD NIGHTS

$$N_{rad} + Q_{heat} + Q_{resp} + C_a \cdot H = C_a (Q_{cc} + Q_{renv} + L_E) + Q_{phot} + Q_{evap} + Q_{soil} \pm Q_{store} \quad [W]$$

Increase

$\downarrow \tau_{ter}$

$\downarrow K_{cc}$

Decrease

$\downarrow R_{en}$

Heating

Double roof

Thermal screen

Structure tightness

ENERGY USE IN GREENHOUSE PRODUCTION

Manage the crop practices and technologies

EFFICIENT RESOURCES USAGE

SUSTAINABLE PRODUCTION

ENERGY AUDITS

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WHAT IS AN ENERGY AUDIT?

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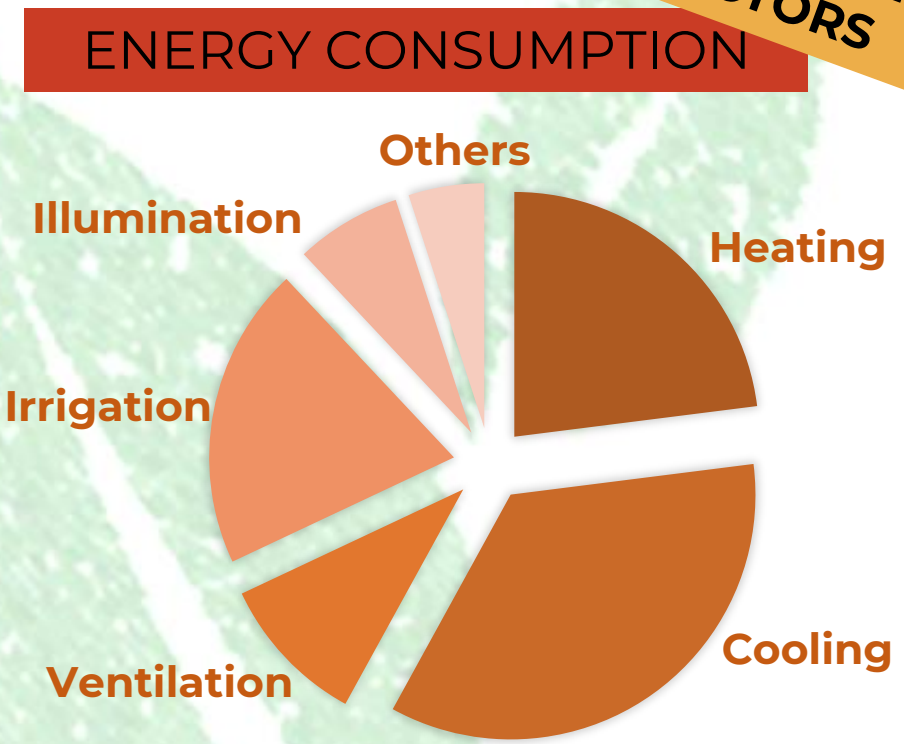
ENERGY AUDIT

An energy audit is a tool that allows to identify where, how and when energy is consumed

Energy saving measures

CRITICAL POINTS

EXTERNAL FACTORS



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ENERGY AUDIT

MAIN GOALS:

- Reduce energy consumption and associated costs
- Reduce GHG emissions
- Identify critical energy consumption points
- Identify improving energy efficiency measures

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GENERAL INSTRUCTIONS FOR ENERGY AUDITS

INSTRUCTIONS

- Plan the audit
- Maintain usual working method
- Prepare a list of documentation required
- Authorize auditors to access facilities and equipment
- Good relationship between employees and auditors

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AUDIT METHODOLOGIES

Phases of an energy audit:

1. Energy pre-diagnosis
2. Energy diagnosis or advice
3. Monitoring diagnosis

Support material

Module Energy Lesson 5.1 - Audits

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ENERGY AUDIT

Equipment and Sensors

Environmental parameters

- TEMPERATURE
- HUMIDITY
- RADIATION
- CARBON DIOXIDE

Energy consumption

- ELECTRICITY
- THERMAL ENERGY
- GAS
- WATER

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EQUIPMENT AND SENSORS

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EQUIPMENT AND SENSORS

(Source:spagnol.com/)

Pyranometer

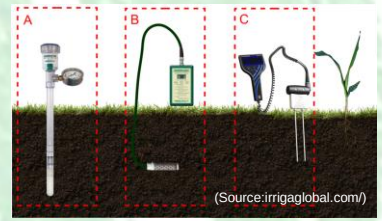
Anemometer

Temperature and relative humidity

Temperature and relative humidity

Carbon dioxide

Soil parameters



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EQUIPMENT AND SENSORS

Climate controller

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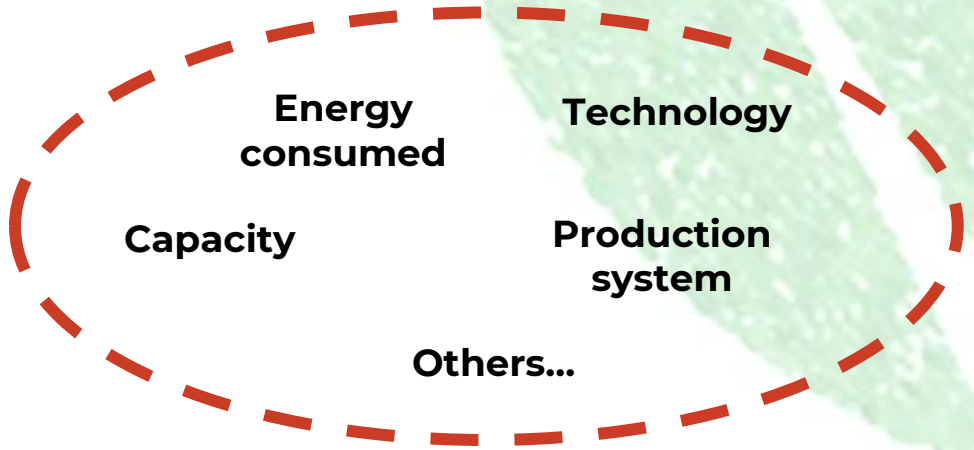
EQUIPMENT AND SENSORS

ENERGY AND WATER CONSUMPTION

- Types
- Complexity
- Prices



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EQUIPMENT AND SENSORS

1 Electricity

Source: circutor.com

2 Thermal energy

Source: sedical.com

3 Gas

Source: aepio.com.br

4 Water

Source: sedical.com

Do you want to learn more?

- Students class
- Additional materials
- Valera, D.L.; Molina, F.D. and Alvarez, A.J. (2008). Protocolo de Auditoría Energética en Invernaderos. Auditoría energética de un invernadero para cultivo de flor cortada en Mendigorría. IDAE, “Ahorro y Eficiencia Energetica en la Agricultura”, 56 pp, ISBN: 978-84-96680-26-5.
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- Stanhill, G., 1980. The energy cost of protected cropping: a comparison of six systems of tomato production. Journal Agricultural Engineering Research 25, 145e154.
- Torrellas, M., Antón, A., López, J.C., Baeza, E.J., Pérez-Parra, J., Muñoz, P. and Montero, J.I. (2012). LCA of a tomato crop in a multi-tunnel greenhouse in Almeria. Int. J. Life Cycle Assess., 17, 863-875.
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Module 5: ENERGY

Lesson 5.1:
Energy audits

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SUMMARY

1. Energy audits

2. Audit methodologis

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WHAT IS AN ENERGY AUDIT?

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ENERGY AUDIT

An energy audit is a tool that allows to identify where, how and when energy is consumed

External factors

↓

Energy consumption

CRITICAL POINTS

Energy saving measures

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ENERGY AUDIT

MAIN GOALS:

- Reduce energy consumption and associated costs
- Reduce GHG emissions
- Identify critical energy consumption points
- Identify improving energy efficiency measures

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GENERAL INSTRUCTIONS FOR ENERGY AUDITS

INSTRUCTIONS

- Plan the audit
- Maintain usual working method
- Prepare a list of documentation required
- Authorize auditors to access facilities and equipment
- Good relationship between employees and auditors

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AUDIT METHODOLOGIES

Phases of an energy audit:

1. Energy pre-diagnosis
2. Energy diagnosis or advice
3. Monitoring diagnosis

1. Energy pre-diagnosis

IMPORTANT

ENERGY AUDIT FORMULARY

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1. Energy pre-diagnosis

BASIC STRUCTURE	
1. General data	6. Production process
2. Energy management	7. Environmental control systems
3. Energy supply	8. Other systems
4. Energy consumption and sales	9. Energy saving systems
5. Energy costs	10. Additional notes

- *Crop*
- *Cropping systems*
- *Productivity*
- *Climatic Local*
- *Greenhouse structural*

Support material:
Energy audit formulary

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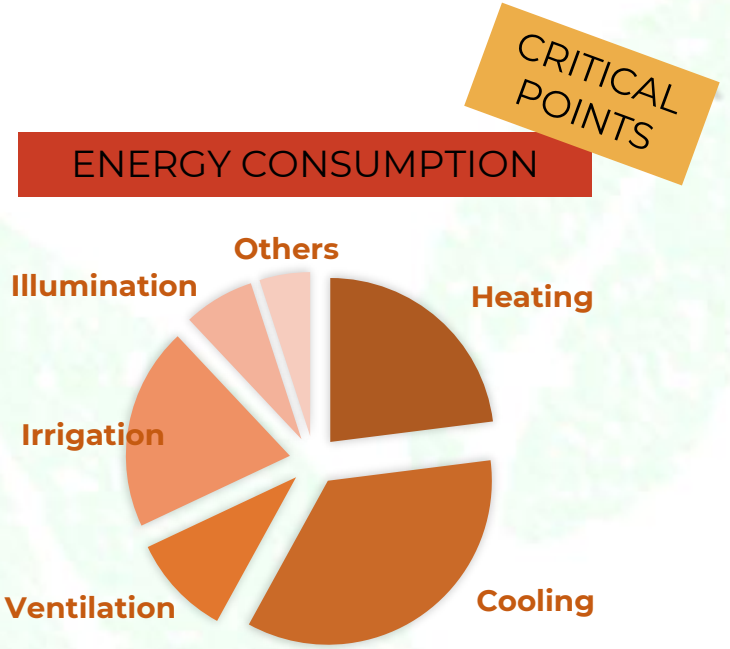
2. Energy diagnosis or advice

- Study of pre-diagnosis data

- Field data collection



- Calculation and evaluation of energy savings

- Preparation of the audit report

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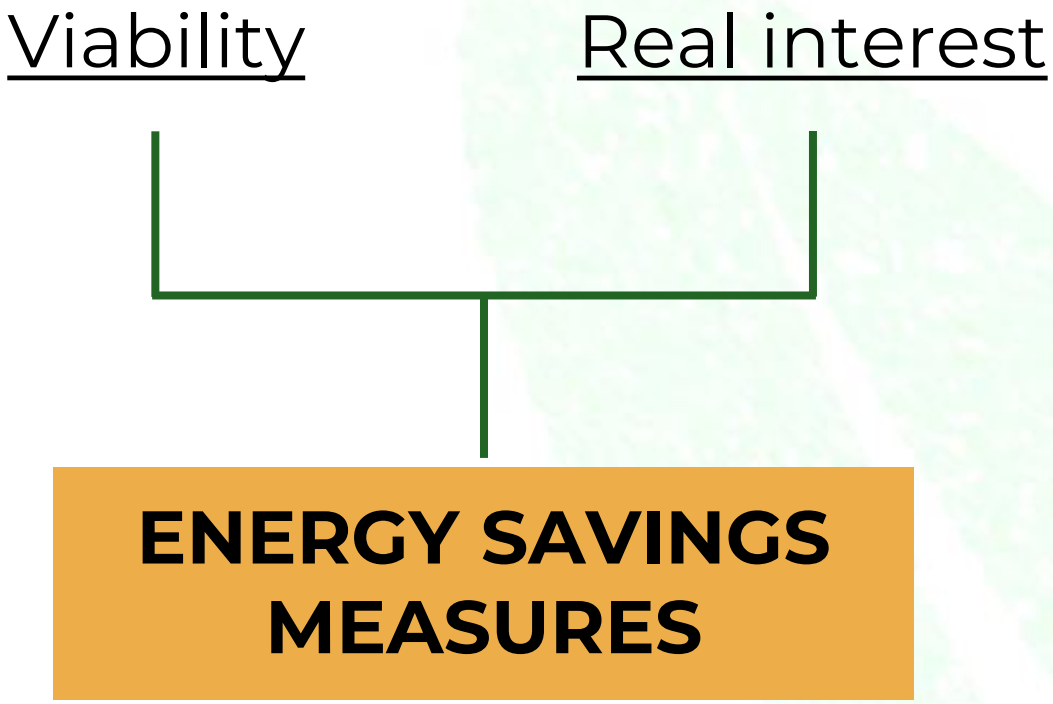
3. Monitoring diagnosis



REFERENCES

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Module 5: ENERGY

Lesson 5.2:
Energy Saving and Energy Efficiency Measures

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SUMMARY

1. Energy use and consumption in greenhouses

2. Energy saving and energy efficiency measures

    a) Building elements

    b) Environmental control equipment

    c) Other measures

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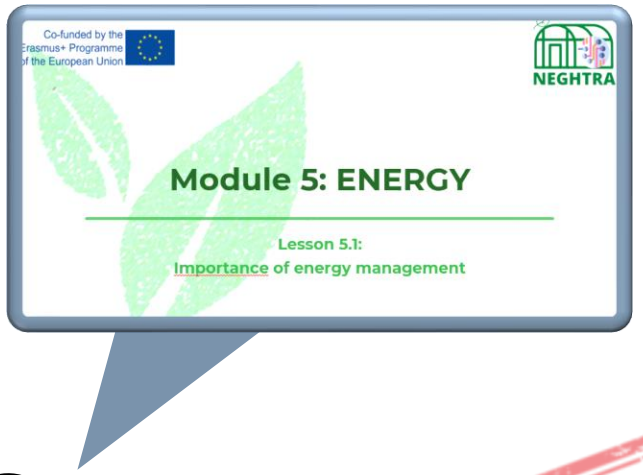
ENERGY USE AND ENERGY CONSUMPTION

ENERGY



FORM

electrical, thermal, mechanical, radiant, kinetic, potential...

SOURCE

solar, wind, nuclear, hydropower, chemical, biomass.....

IMPORTANT

What is energy?

TRANSFORMED AND TRANSMITTED

PHYSICS: CAPABILITY TO DO WORK

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ENERGY

DIRECT ENERGY

INDIRECT ENERGY

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ENERGY USE IN GREENHOUSE PRODUCTION

Direct Energy:

used directly: diesel used in machinery, energy used for climatization, lighting, irrigation systems, etc. (electricity, natural gas).

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ENERGY USE IN GREENHOUSE PRODUCTION

Indirect Energy:

used for the inputs production including fertilizers, agrochemicals and auxiliary materials (thermal screens, plastic films, irrigation pipes, etc.).

1. Energy use

2. Energy saving and energy efficiency measures

Government's GOALS:

- Supply security
- Reduce energetic dependence
- Economic and environmental sustainability
- Compliance with international commitments

Energy efficiency

Renewable energies

Key targets for 2030:

- At least 40% cuts in **greenhouse gas emissions**
- At least 32% share for **renewable energy**
- At least 32.5% improvement in **energy efficiency**

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What is energy efficiency?

Does energy consumption reductions means improvement in energy efficiency?

ENERGY EFFICIENCY

World Energy Council

Reduction in the energy used for a given service or level of activity

AGREE project

Decrease of primary energy consumption for the production of a unit of agricultural product within the farm boundaries

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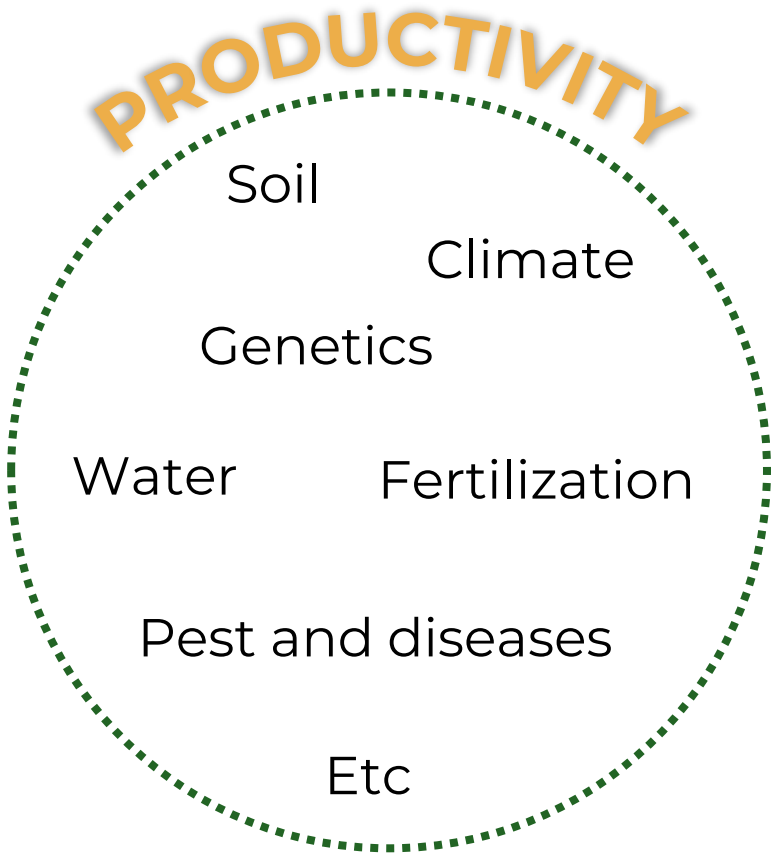
Agriculture sector



- Energy
- Environmental
- Economic

Energy efficiency

+ Renewable energies

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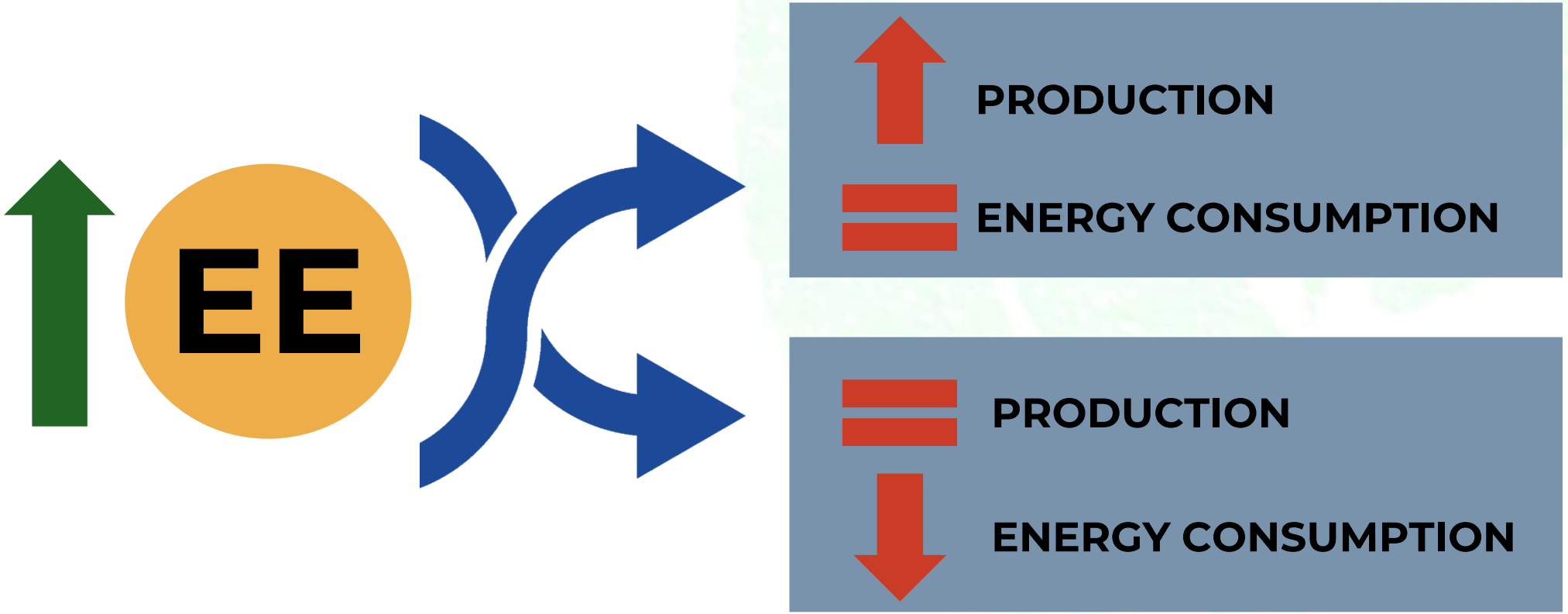
How to increase energy efficiency?



EE Indicators

- Direct and indirect energy consumption
- Total energy consumption
- Specific energy
- Energy productivity
- Output/Input

ENERGY DEMAND IN GREENHOUSE PRODUCTION

Environmental control systems

- Create adequate climate condition to grow plants
- Automation control systems

INPUTS

Fertilisers, agrochemicals, building materials, irrigation materials, ...

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Energy consumption in tomato greenhouse production

1. Energy use

2. Energy saving and energy efficiency measures

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The Netherlands	0.0	99.3	0.7	0.0	0.0

(Source: Meyer-Aurich et al, 2012)

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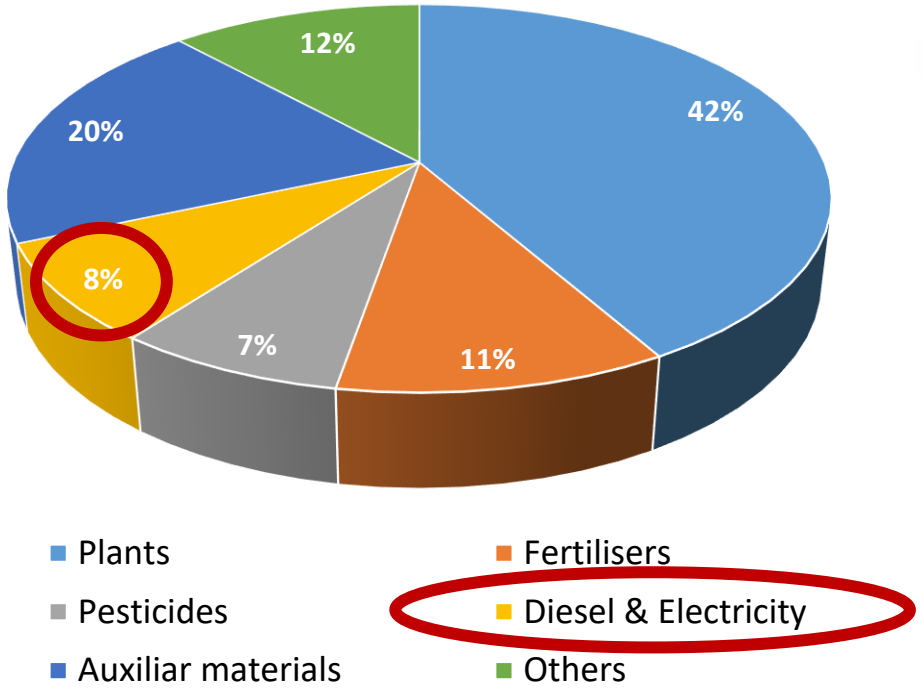
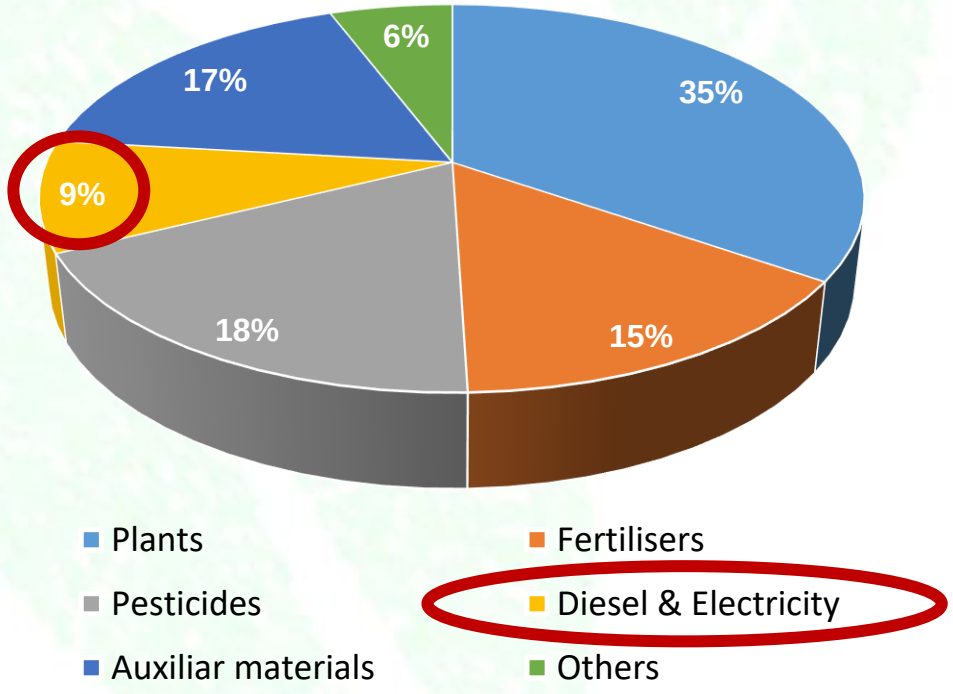
1. Energy use

2. Energy saving and energy efficiency measures

Tomato greenhouse production costs in Portugal (A) and Spain (B)



A. *Figure elaborated with data from Baptista et al., 2012 in Meyer-Aurich et al., 2012*



B. *Figure elaborated with data from Molina-Aiz et al., 2020*

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ENERGY AUDIT

It's a tool that allows to identify where, how and when energy is consumed in an installation

Energy saving measures

Main goals:

- Reduce energy consumption and associated costs
- GHG emissions
- Identify critical energy consumption points
- Identify improving energy efficiency measures

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ENERGY SAVING AND ENERGY EFFICIENCY MEASURES

Energy saving and energy efficiency measures

Main focus

- Building
- Climatization equipment
- Lighting
- Rational use of inputs

Heat losses

- *Cover material*
- *Ventilation*

Increase thermal insulation

Reduce infiltration

Investment

Grower choices, crop practices and available technologies

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Energy saving and energy efficiency measures

a Building elements

b Environmental control equipment

c Other measures

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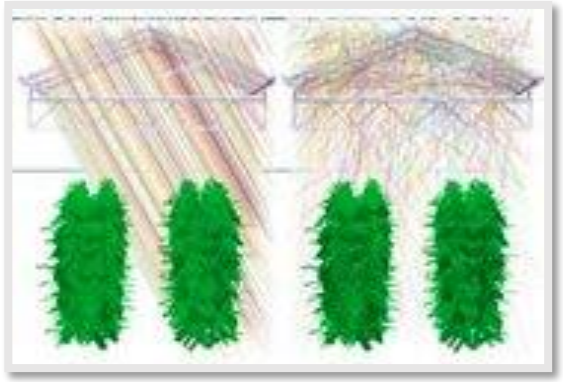
a) Building elements

1. Maximize the light and its quality

- Use cover with high transmissivity to PAR radiation
- Greenhouse cover with good diffusion and anti-dripping effect
- Optimize greenhouse cover slope and orientation
- Clean and change the plastic in the right moment



(Source: Swinkels, 2016)

(Source: Baeza and Kacira, 2015)

2. Minimize the heat losses from the greenhouse

- Double or triple cover
  - Reduce heat losses by 40-50% and energy costs by 30-40%
  - Increase of the minimum night temperature
  - Reduce temperature and relative humidity fluctuations
  - Reduce light transmission by approximately 10%

2. Minimize the heat losses from the greenhouse

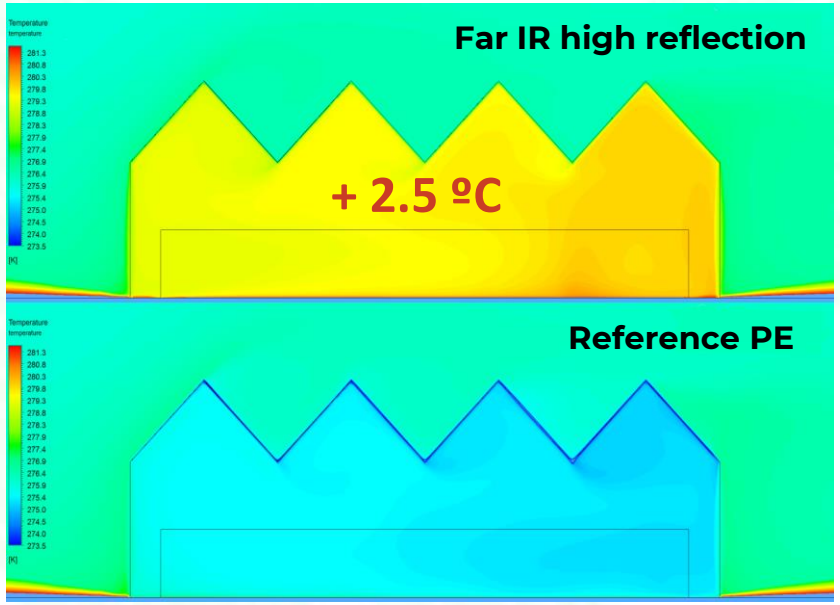
Thermal screens

- Reduce nocturnal heat losses by 35 - 40%
- Can be combined with heating
- Shading screens during day period
- Reduction of infiltration (humidity increase – diseases)

2. Minimize the heat losses from the greenhouse

- Micro tunnels

- Materials with high reflection to radiation



(Source: Piscia et al., 2013)

- Wind barriers

b) Environmental control equipment

Ventilation
Cooling
Heating

- Create adequate climate
- Automation control systems

Knowledge

- Plants physiological processes
- Environmental factors (light, temperature, humidity and CO_2)

Environmental control systems

- Correctly designed
- Frequently checked and maintained

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Ventilation

Natural ventilation

Mechanical ventilation

Control of air temperature, air humidity and avoid CO_2 depletion.

If mean t_{out} < 27°C ventilation is enough for temperature control

Mediterranean contries (spring / autumn)

close greenhouses late in the afternoon in order to reduce heat losses.

IMPORTANT

Air humidity

Diseases development

Ex: Botrytis cinerea

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1. Energy use

2. Energy saving and energy efficiency measures

2a. Building elements

2b. Environmental control equipament

2c. Other measures

- Roof vents
- Lateral Roof vents
- Roof and lateral vents

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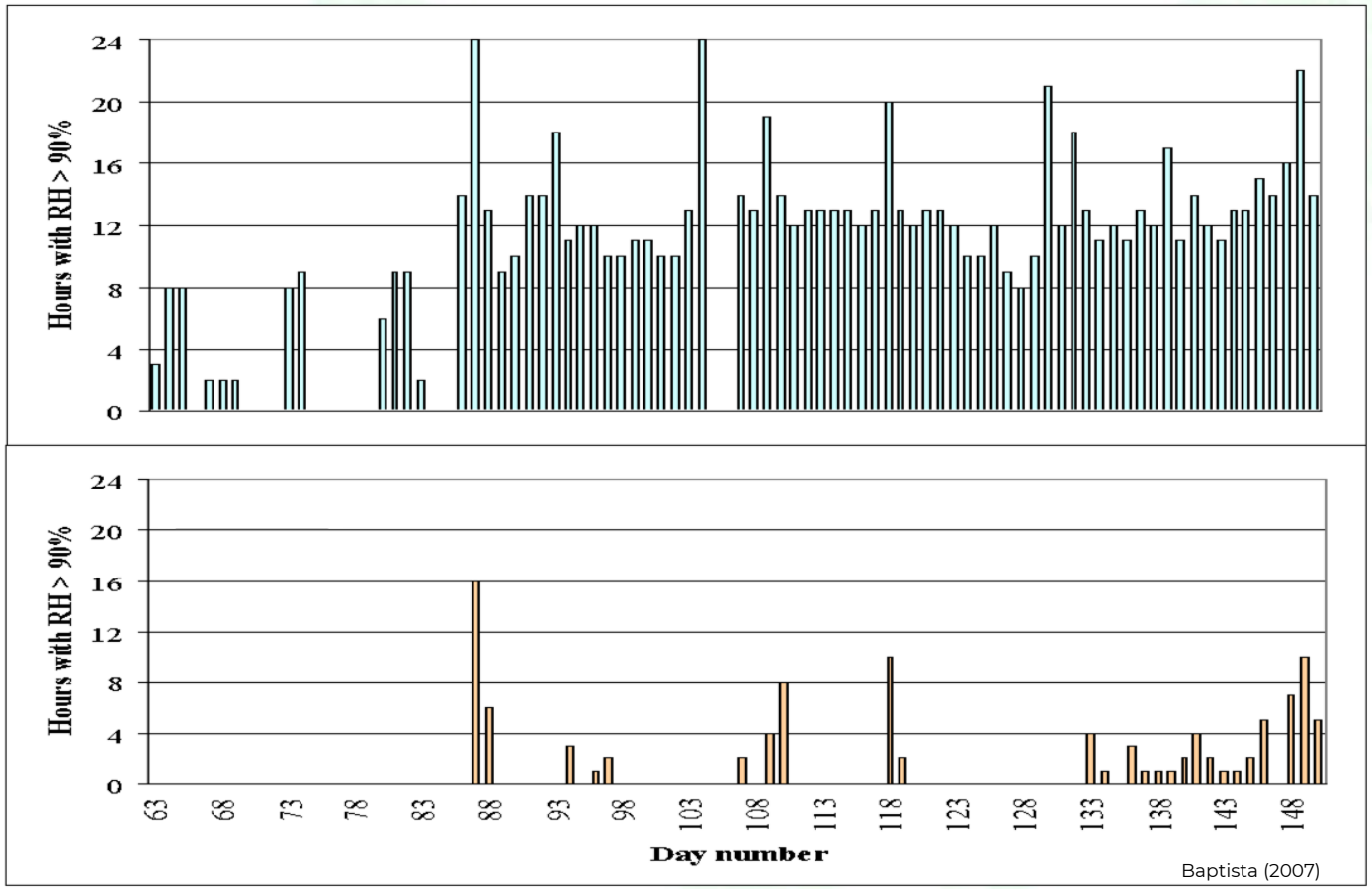
Ventilation

No nocturnal ventilation
(closed greenhouse)

Permanent ventilation

Hours per day with RH > 90%



Baptista (2007)

No nocturnal ventilation – 904 h x **Permanent Ventilation – 104 h**

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Ventilation

Mean temperature (°C) for day, night and 24 h periods

		Day	Night	24h
Year 1	No nocturnal ventilation	21.7±0.3	13.2±0.3	16.3±0.2
	Permanent ventilation	21.9±0.3	13.3±0.2	16.5±0.2
Year 2	No nocturnal ventilation	22.5±0.4	14.3±0.3	17.1±0.3
	Permanent ventilation	22.6±0.4	14.1±0.3	17.0±0.3

(Baptista, 2007)

Ventilation nocturnal

→ *economic*

→ *environment*

→ *energetic*

Cooling Systems

Ventilation

+

Shading

+

Evaporative cooling

Adapted from: https://www.youtube.com/watch?v=iOem-VRTQws

8 to 10 °C

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Cooling Systems

❑ Shading screens

- Reduce heat gains due to solar radiation and with that the energy needs for cooling (30 - 40%)

- Placed inside or outside the greenhouse (wind resistance)

Cooling Systems

❑ Evaporative cooling

- **Fog systems**

More uniform and doesn't need mechanical ventilation

  - Spray water
  - High efficiency of water evaporation
  - Dry foliage

- **Pad and fan**

  - Extractors and wet panels
  - Remove inside air
  - Outside air passing through panels

Heating Systems

(Source: pericolic.com)

Mediterranean regions (winter)

- sometimes it is necessary to heat the greenhouses during the night period

(Source: alcomij.com)

Maximize production

Increase product quality

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Heating Systems

(Source: pericolic.com)

- Extend production period
- Anticipate harvesting
- Production out of season
- Increase productivity and quality
- Energy consumption and GHG emissions
- Crops needs, crop cycle, climate conditions, solar radiation and production period

(Source: alcomij.com)

- If tout < 10°C usually heating is required, mainly during the night
- Energy sources: natural gas, diesel, biomass, electric, solar and wind

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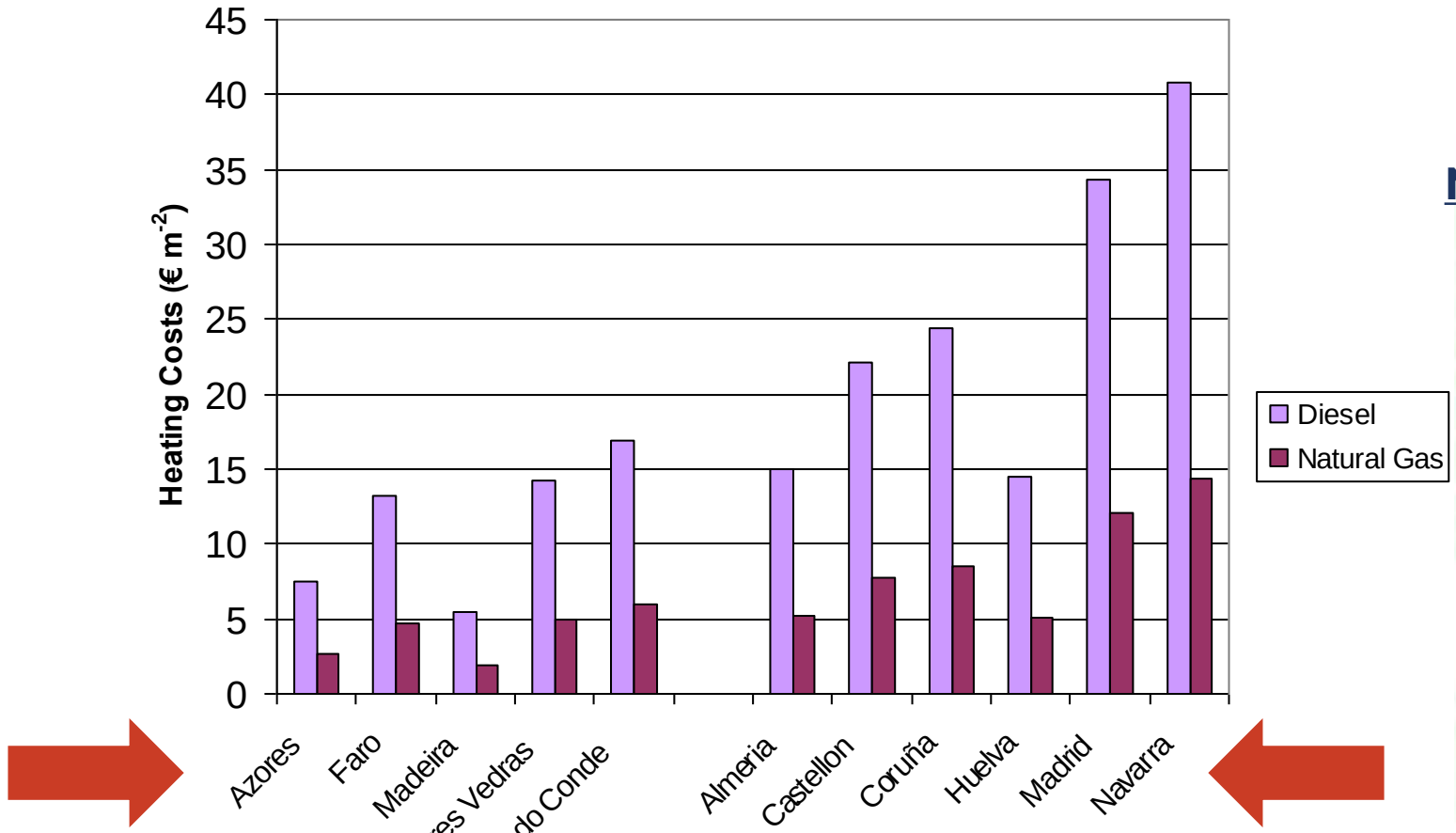
Heating Systems

DIESEL *vs* NATURAL GAS



Natural gas → **Diesel**

35% cost €

(Source: Baptista et al.. 2012)

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c) Other measures

- Closed irrigation and fertigation systems
- Rationalize the use of fertilizers and water in greenhouse production
- Use of integrated control systems
- Monitoring and control systems

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Case study

Reference	Tomato crop grown on soil
1 - Hydro	Tomato crop grown in substrate
2 - Hydro_FW	Hydroponic with reduction of 35% N, 20% P_2O_5, 17% K_2O and 20% water
3 - FPW	Soil: reduce of 30% fertilisers, 20% Water and 20% agrochemicals
4 - ICS	Integrate Control System

Baptista et al. (2012)

Portugal

Rational use of inputs: saving energy

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Case study

	Annual costs (%)	PEC – (%) Primary energy consumption	GHG (%)
Reference	100.0	100.0	100.0
1 - Hydro	107.2	164.0	165.4
2 - Hydro_FW	104.5	138.9	135.8
3 - FPW	96.7	85.0	82.8
4 - ICS	100.2	90.9	91.9

Baptista et al. (2012)

RESOURCES USE EFFICIENCY

Increase yield and product quality

- Crop practices
- Improving greenhouse structures
- Implementing technology for climate control

ADAPT TECHNOLOGY

NOT ADOPT (WITHOUT PREVIOUS TESTING)

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1. Energy use

2. Energy saving and energy efficiency measures

2a. Building elements

2b. Environmental control equipament

2c. Other measures

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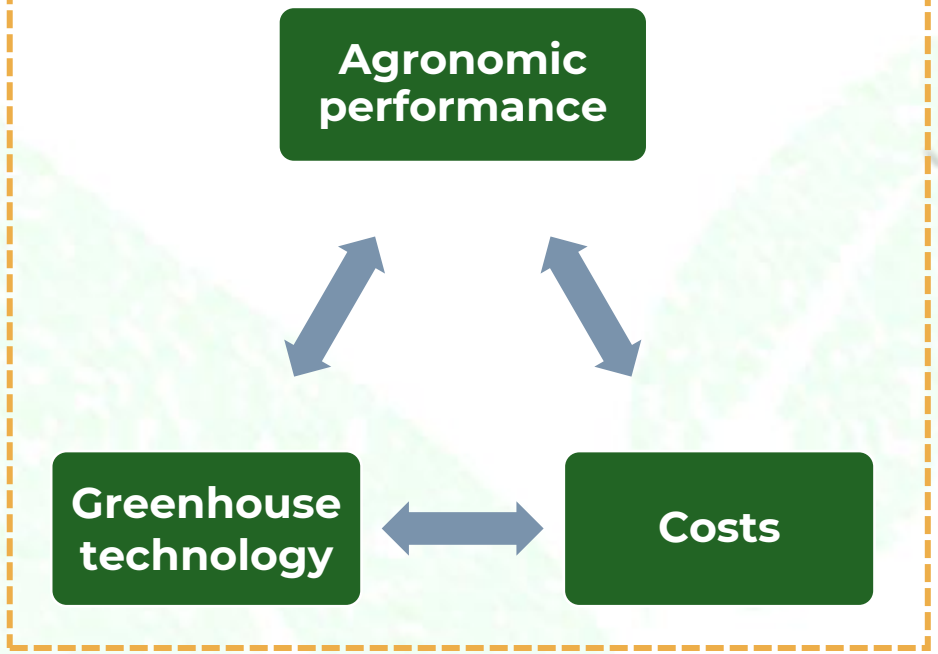
IMPORTANT

Local technical and socio-economical conditions



SUSTAINABLE SOLUTIONS

FINAL CONSIDERATIONS

In order to save energy and improve efficiency, it is very important to:

- understand what is sustainable production
- be aware of total energy consumption (direct + indirect)
- design and maintain climate control equipment
- promote the use of monitoring and automation control systems
- alert growers and associations to the importance of saving energy and resources efficient use
- promote knowledge transfer and dissemination of good practices

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Energy

Energy Saving and Energy Efficiency Measures

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