GROOF
Greenhouses to Reduce CO_2 on rooFs

Energy and Material Flows in Rooftop Greenhouses

Overview GROOF project

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IfaS Institut für angewandtes Stoffstrommanagement

Interreg North-West Europe GROOF

Introduction

"Energy is the capability of a system to make an action"

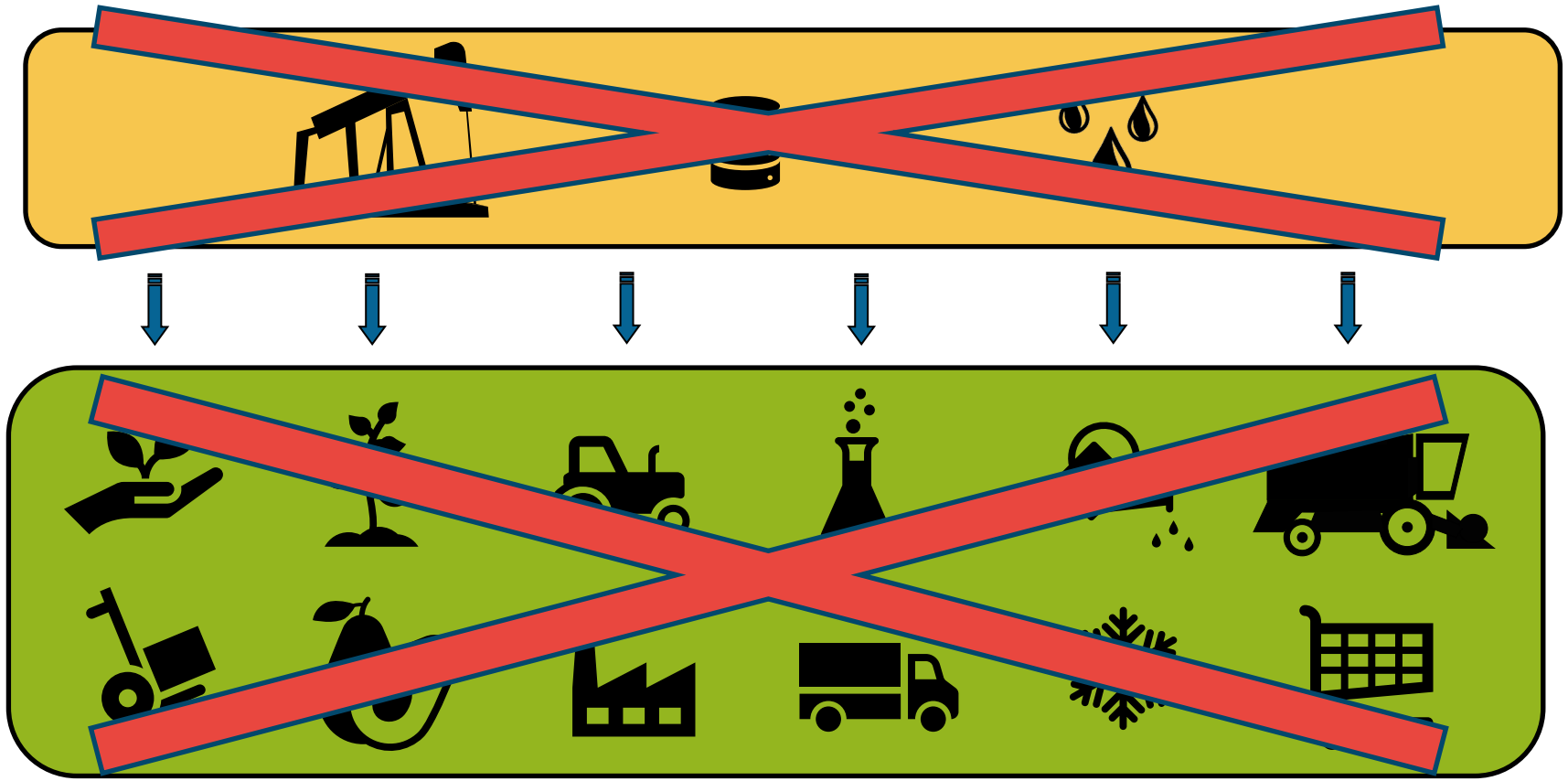
-loosely based on Max Planck

FOOD = ENERGY

Introduction

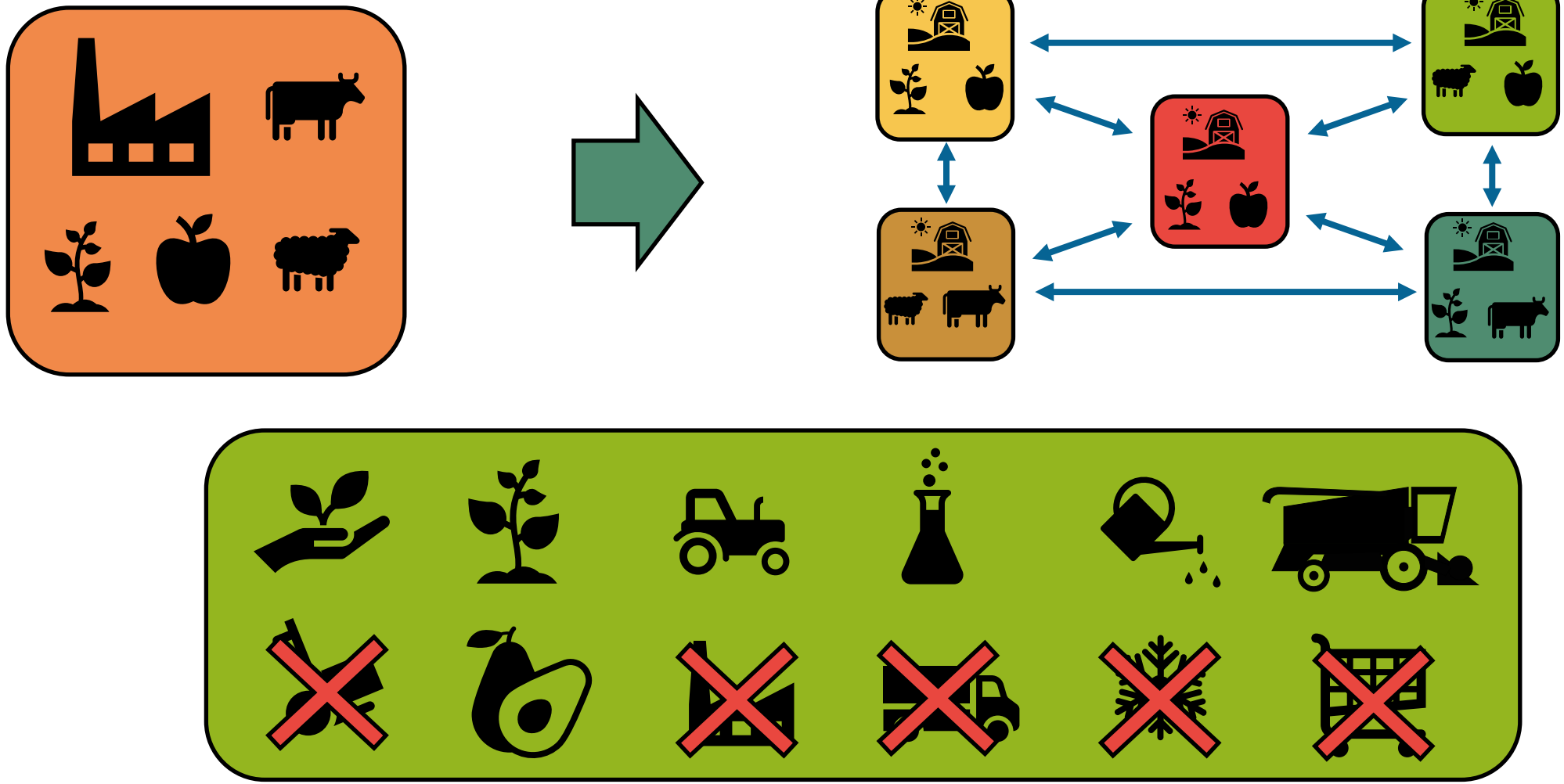
FOOD = FOSSILE ENERGY

No Oil …



No Food!

Introduction



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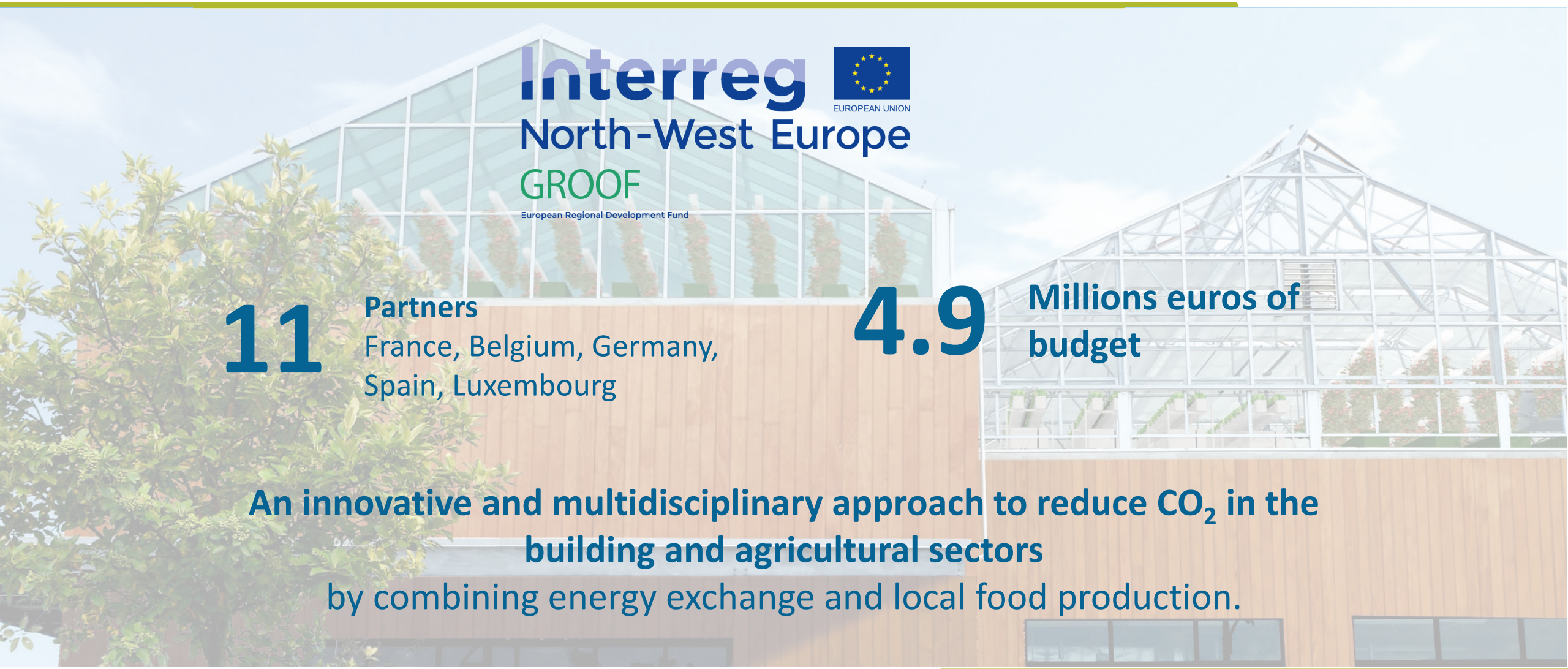

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EUROPEAN UNION
North-West Europe
GROOF
European Regional Development Fund

11 **Partners**
France, Belgium, Germany, Spain, Luxembourg

4.9 **Millions euros of budget**

An innovative and multidisciplinary approach to reduce CO_2 in the building and agricultural sectors
by combining energy exchange and local food production.

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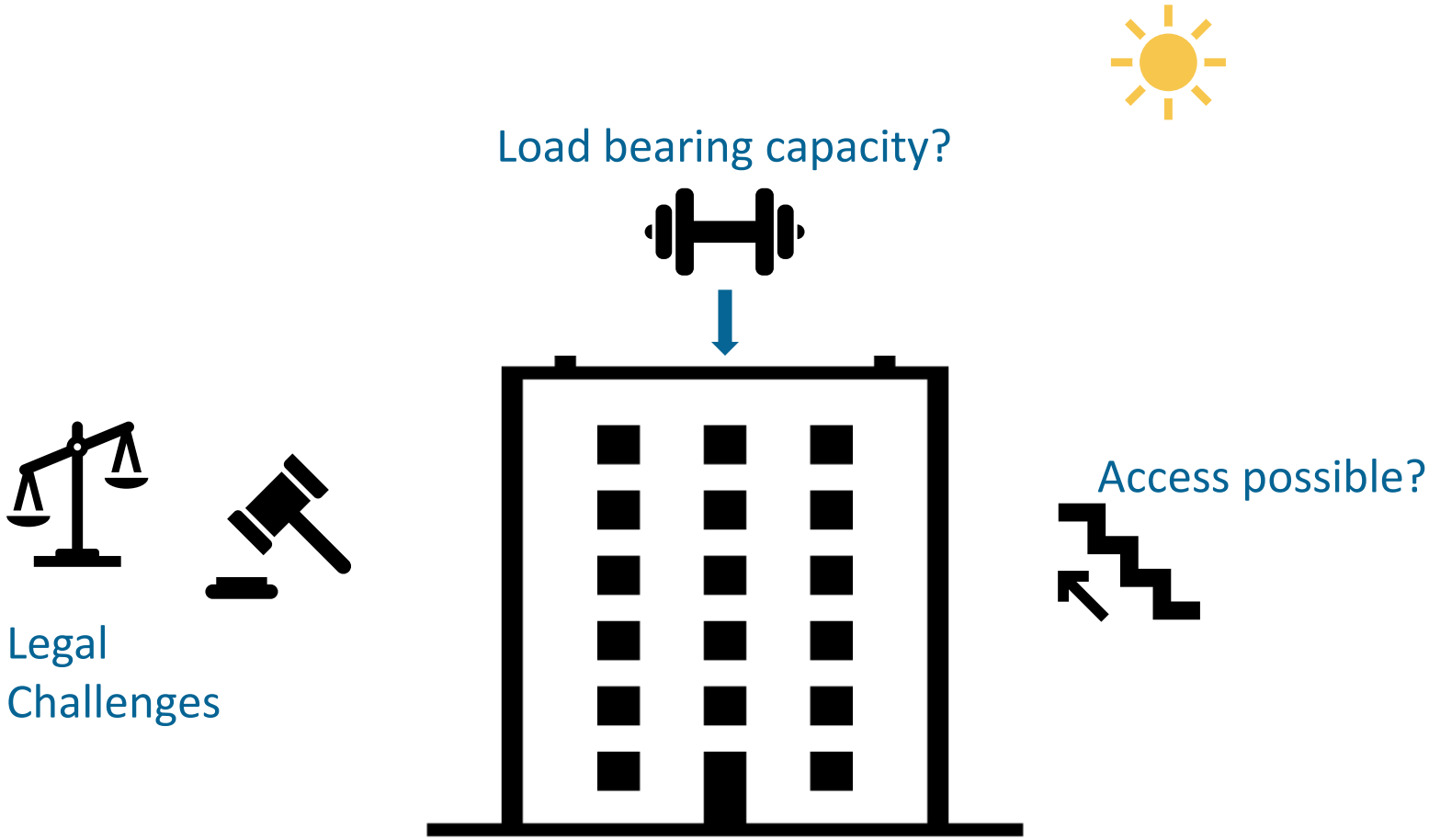
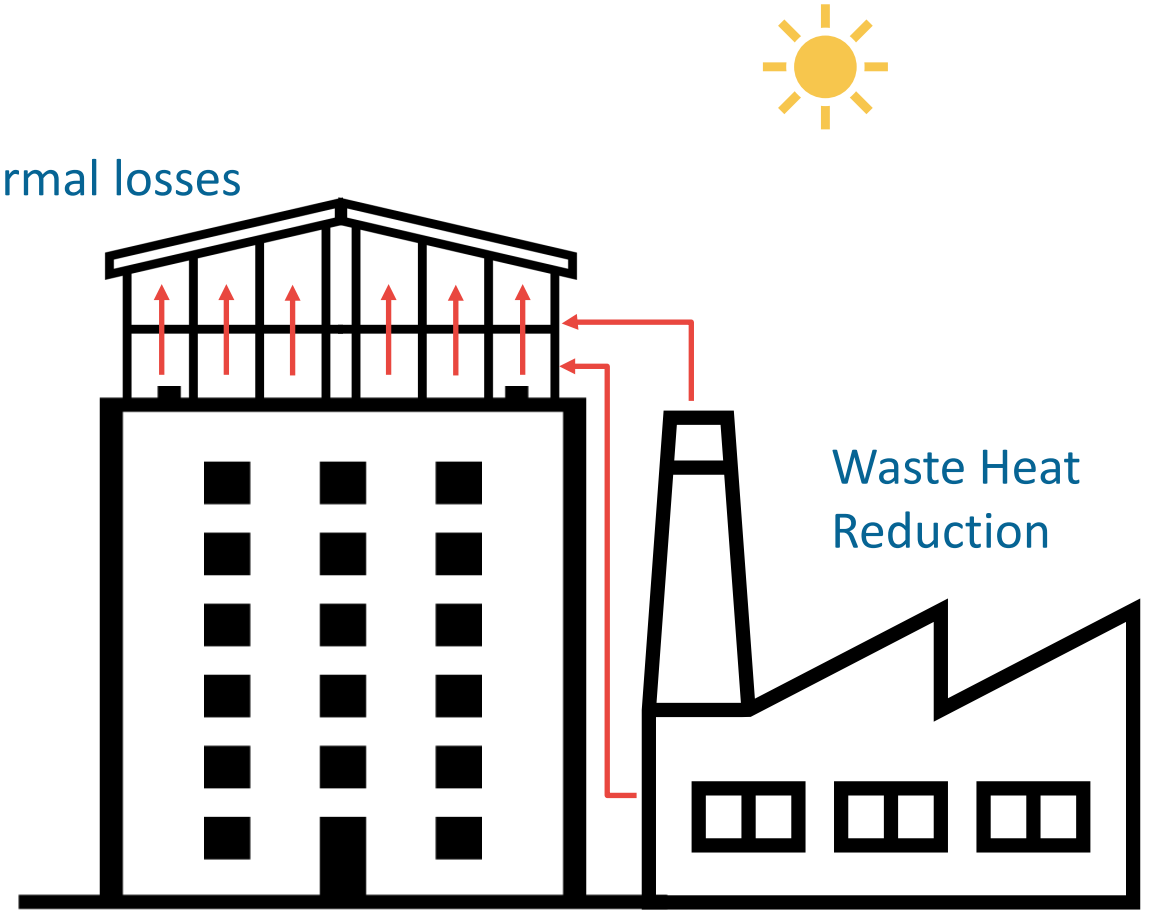
The GROOF idea

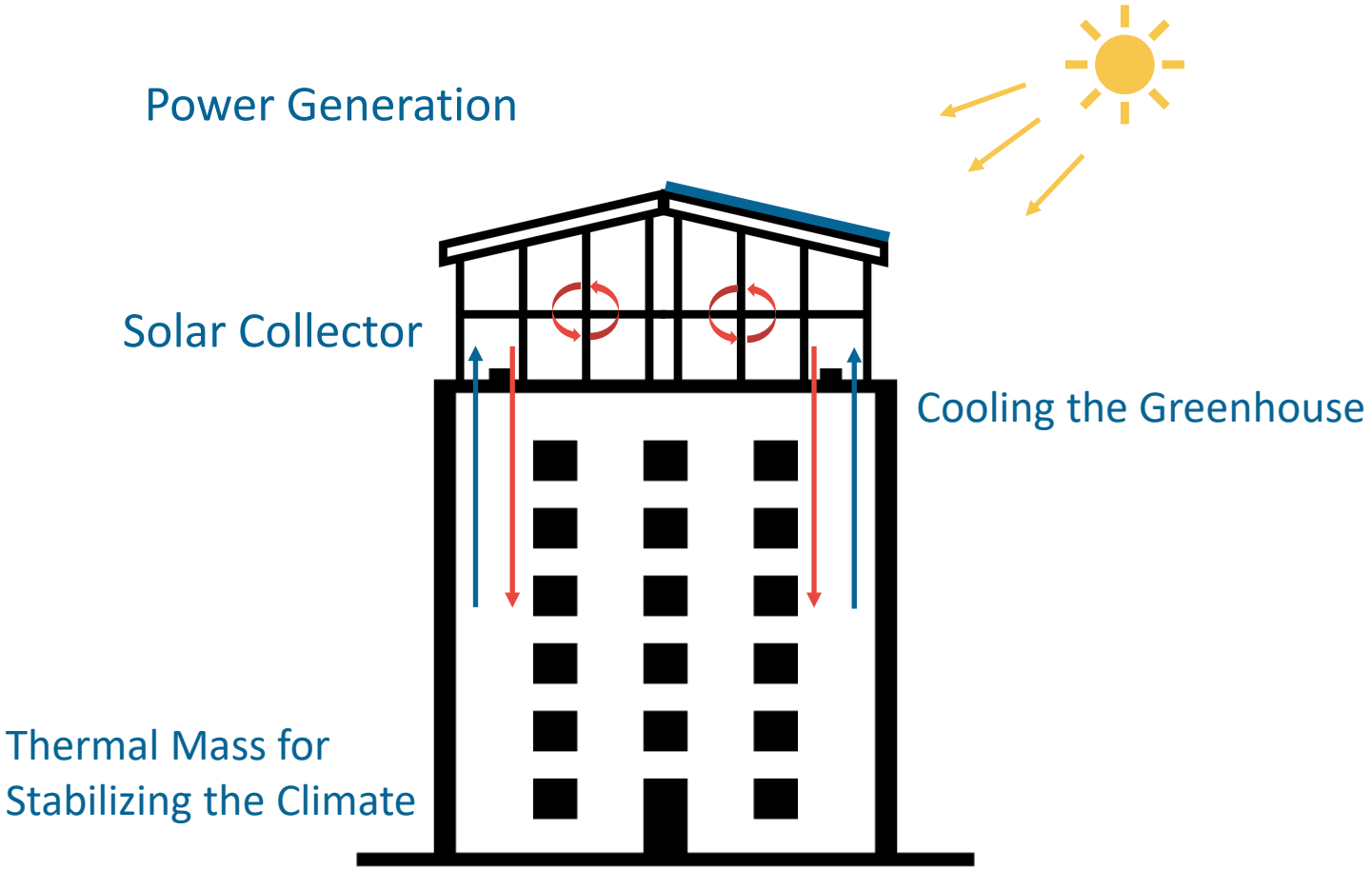


The GROOF idea

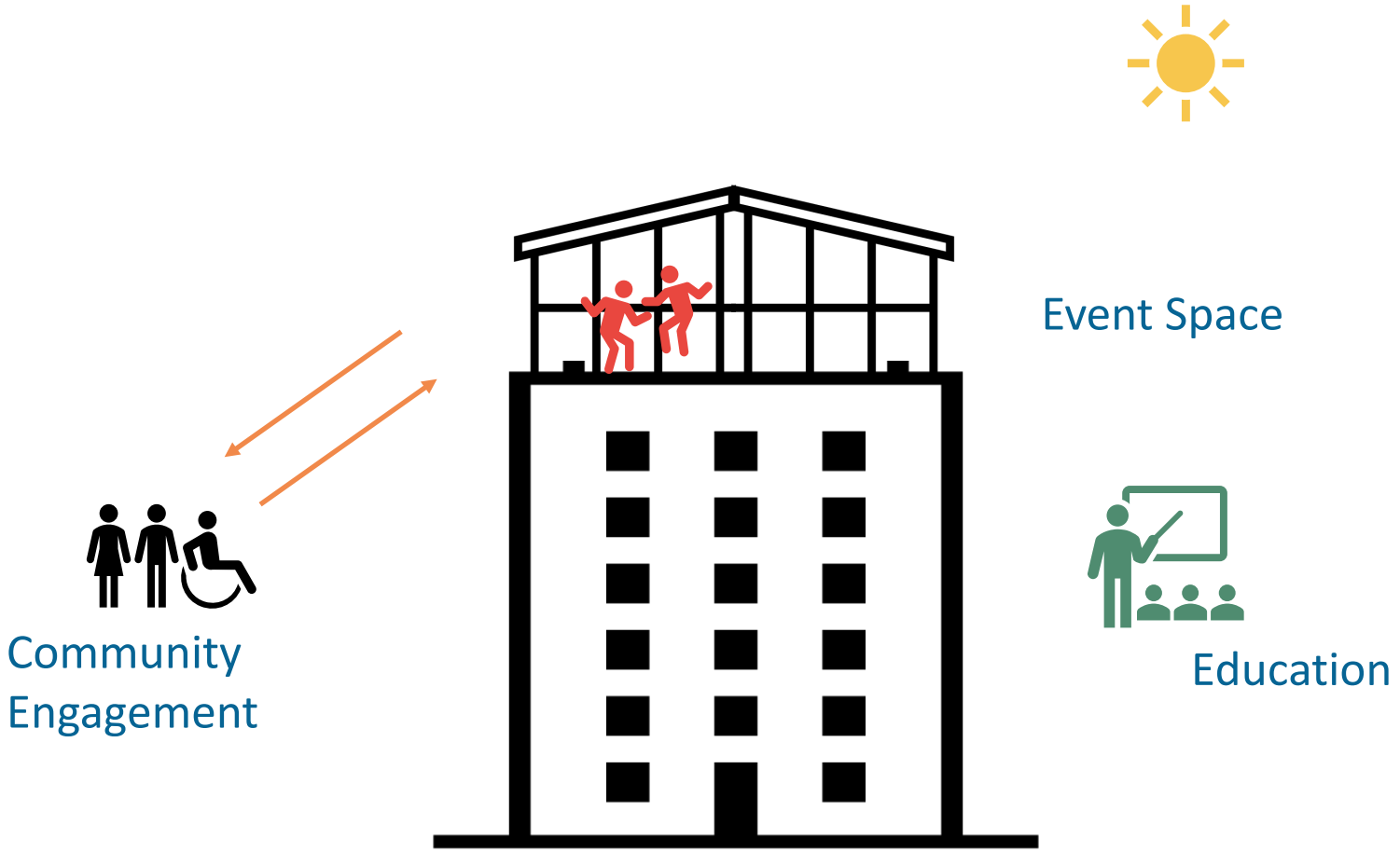
Reduction of thermal losses



The GROOF idea



The GROOF idea



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The GROOF idea

Barcelona (ES)

sostenipra

UAB
Universitat Autònoma de Barcelona

ICTA Institut de Ciència i Tecnologia Ambientals - UAB

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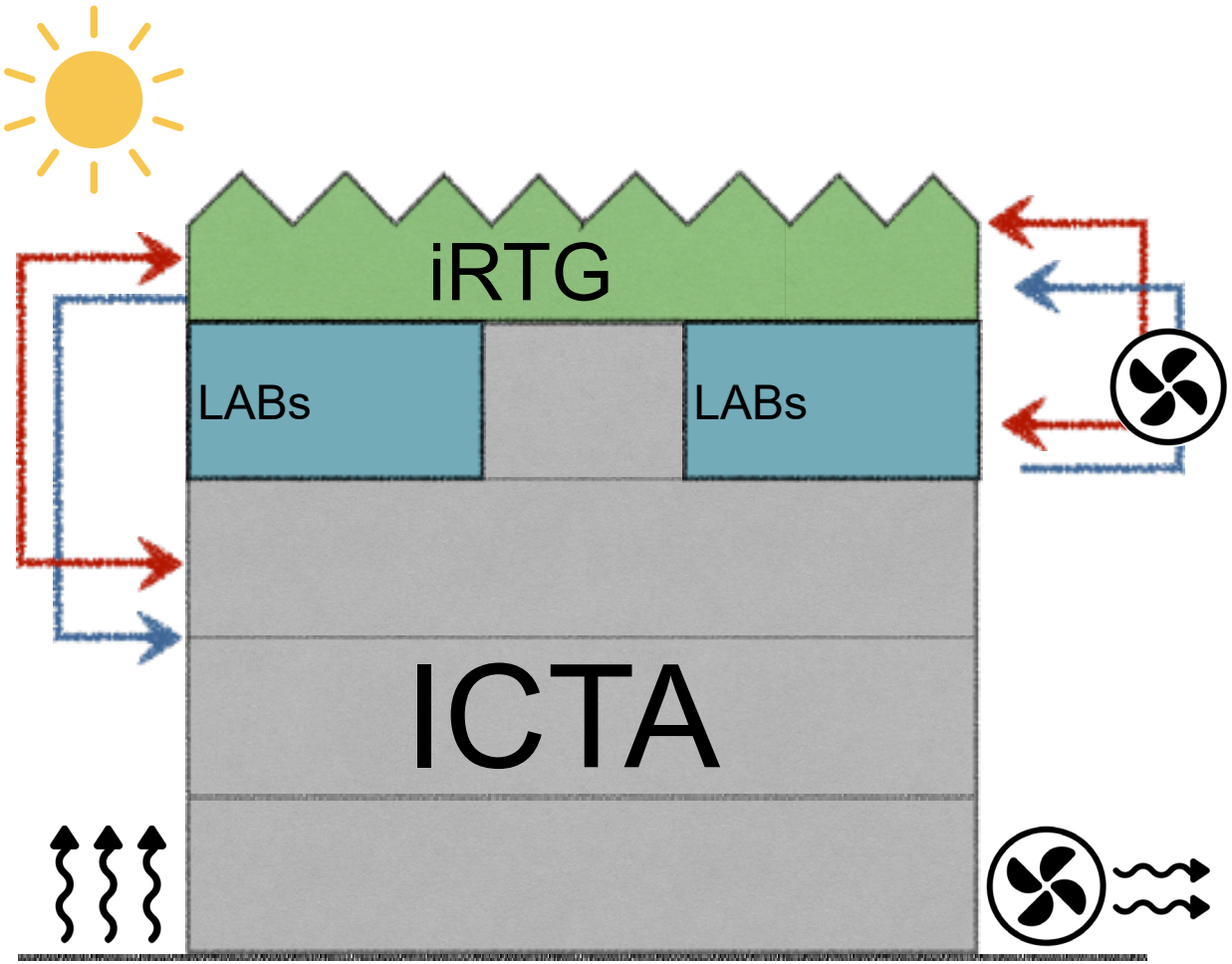
The GROOF idea

recovered by the greenhouse

98 kWh/m²

32 kWh/m² 13 kWh/m²

insulation effect



gained to the greenhouse

63 kWh/m² 16 kWh/m²

59 kWh/m²

gained to the building

Natural energy flows

Forced energy flows

(Nadal et al., 2017; Muñoz-Liesa et al., 2021)

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LES FERMES DE GALLY

Saint-Denis (FR)

Bettembourg (LU)

IFSB

SMART CITY INSTITUTE HEC Liège

Centre de Recherches en Agriculture Urbaine

LIÈGE université

Gembloux (BE)

Bürstadt (DE)

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The building and greenhouse design

Industrial warehouse (yellow)

→ Low load capacity of the rooftop (technically feasible, expensive)

Offices and school (red)

→ The greenhouse design is not suitable in terms of energy efficiency
→ Poor ratio of 2,4 between the envelope and the surface area
→ No insulated wall on the north side of the building
→ The quantity of waste heat has not a high effect on energy savings (5 -10%)
→ Installation would affect the waterproof layer

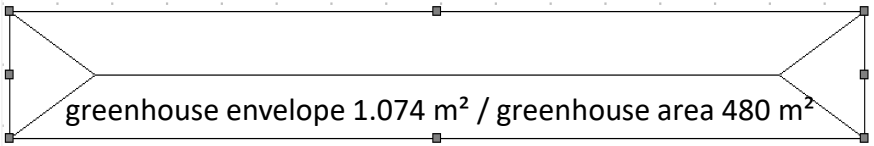
New building for the canteen (blue)

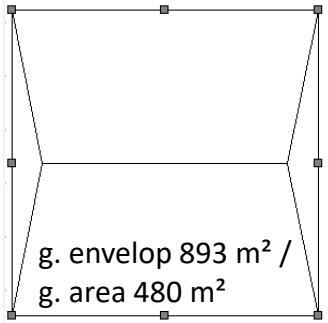
Advantages:

→ High load capacity of 500 kg/m²
→ The greenhouse design is perfect in terms of energy efficiency
→ Access to waste heat
→ Access to CO_2 from ventilation system for the fertilization of plants
→ Potentials for PV-Systems

Disadvantages:

→ Shadow in the mooring from the neighbor building
→ Modification of the boiler system

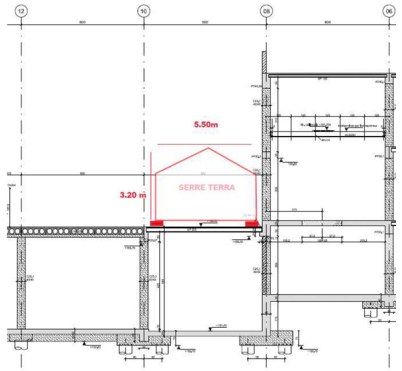


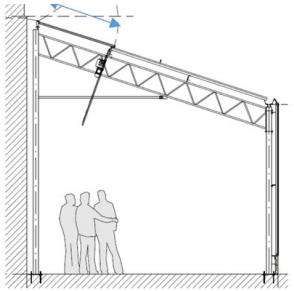


Energy consumption depends on the greenhouse design

Singel glaz greenhouse (1 energy screen)	[kWh/m²]
Greenhouse ratio 2,2	457
Greenhouse ratio 1,8	349

Building and greenhouse design





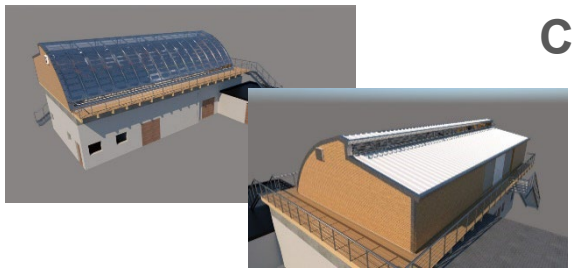
Examples greenhouse design (GROOF)
(In this case exists disadvantages of a gabled RTG)

Gabled roof type:

→ The weight of the gabled greenhouse structure is higher than the lean-to type
→ For the installation of the steel beams, a wide opening of the waterproof layer is necessary
→ A higher energy demand than the lean-to type (13%)
→ A higher investment

Lean-to roof type :

→ The lean-to RTG type can be installed without damaging the waterproof layer
→ A higher efficiency (lower enveloped area)
→ A lower investment



Chinese Lean-To Greenhouse (EBF)

→ Energy saving greenhouse (80-90% compared to commercial greenhouse)
→ Solar greenhouse (PV-System)
→ Use materials with a low U-value

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Building and greenhouse design

Heat protecting glass

Advantages:

- long lifetime (no replacement)
- Energy savings 60-70%

Disadvantages:

- Light reduction 10%
- Cost intensive
- Installation of other components are difficult (e.g. heating pips in the roof area)
- High weight

Foil (double) f-clean-foil

Advantages:

- Energy savings 60%
- Relative long lifetime
- High transparency
- Cost-efficient alternative (Compared to the other materials)
- High crop quality (is possible)
- Low weight

Disadvantages:

- Plastics are degraded by the radiation
- Replacement on the rooftop is cost intensive
- Germany greenhouse insurance is based on current value

Polyc. sheets (4 layers) combi. heat protecting glass

Advantages:

- Energy savings 70%
- Glass has long lifetime

Disadvantages:

- Plastics are degraded by the radiation
- Replacement on the rooftop is cost intensive
- Germany greenhouse insurance is based on current value
- Light reduction

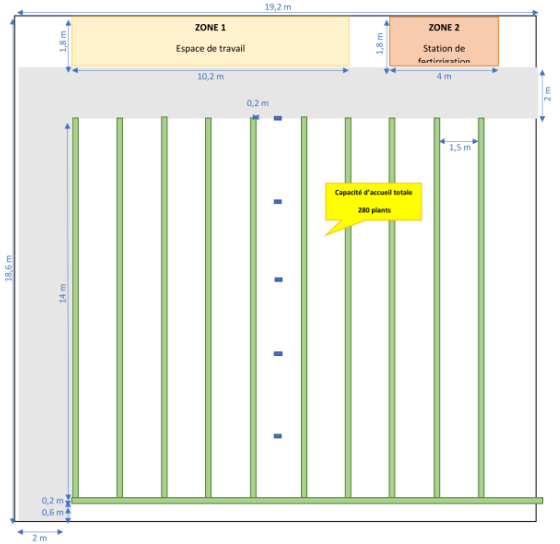
Thermal screens

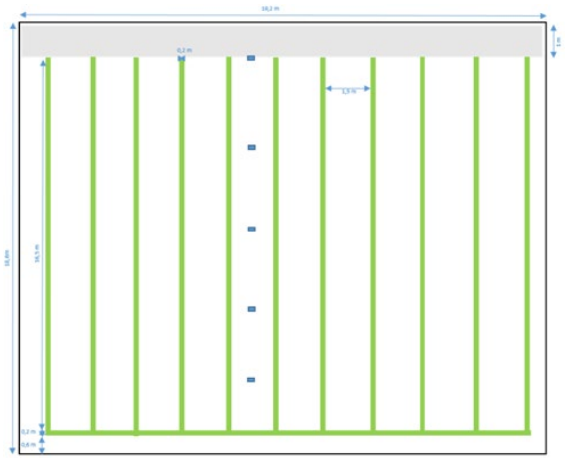
Advantages:

- Energy savings
- Cost efficient
- Day / Thermal screen
- Reduce the negative impacts of wind speed

Disadvantages:

- Replacement after 10-15 year
- Germany insurance is based on current value
- Light reduction

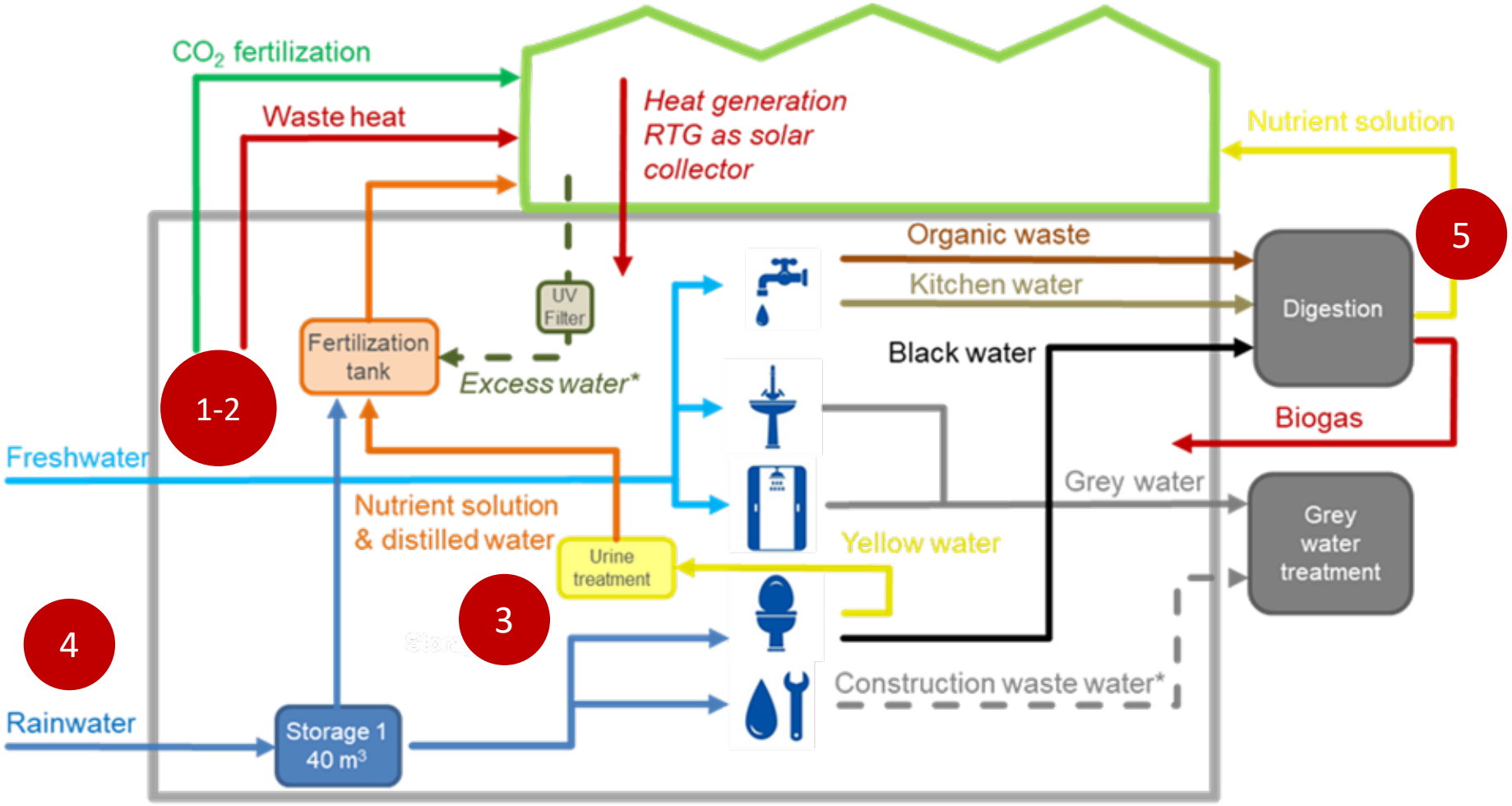




- **RTG production:**
  - The area allocation is based on the unproductive area of 140 m²
  - Decreasing the harvesting rate per m² and the economics
  - Reduction of areas pathways, workplace and fertilization
- **Solution:**
  - Fertilization and workplaces cloud be shift to the basement
  - Reduce the pathway on the left side
  - Unproductive area is around 20 m²
  - Additional option of vertical farming on the north wall exist
- **Calculation example**
  - RTG area = 380 m² / Production area 260 m²
    → Corp harvesting rate 30 kg/m²*a = yield of 7.800 kg/a
  - RTG area = 380 m² / Production area 360 m²
    → Corp harvesting rate 30 kg/m²*a = yield of 10.800 kg/a

The efficient greenhouse usage
has also an influence on the efficient energy usage

Potential analyse



*Occurence and composition of material flows is unknown

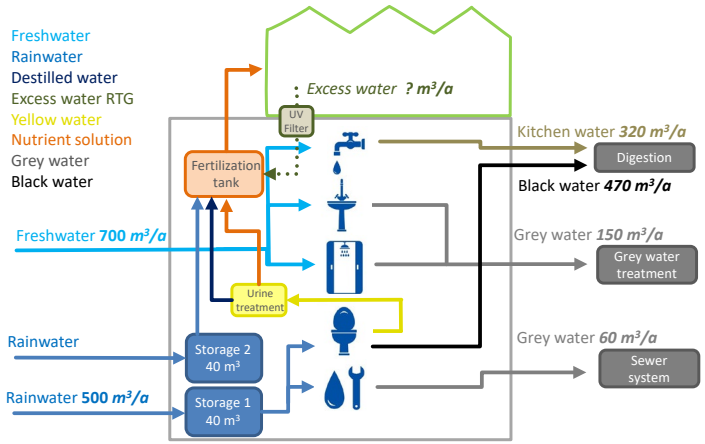
Potential analyse energy

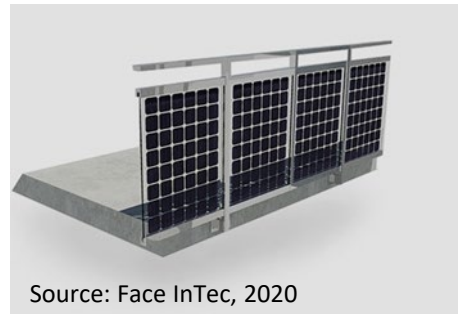
Potential analyse of the building (theoretical potential)

- Waste heat potential from the ventilation system (canteen)
  → assumption of 10.000 – 30.000 kWh/a (depends on the usage)
- CO_2 fertilisation through exhaust air stream from offices (main building)
  → CO_2 content between 450 and 700 ppm during the day
  (Benoit Martin; Construction Certification S.A (COCERT), 2019)
  → For crops, a CO_2 level of 500 - 700 ppm is desired
- Water and Fertilizer:
  → Rainwater; Waste water; Urine

Further / future potentials

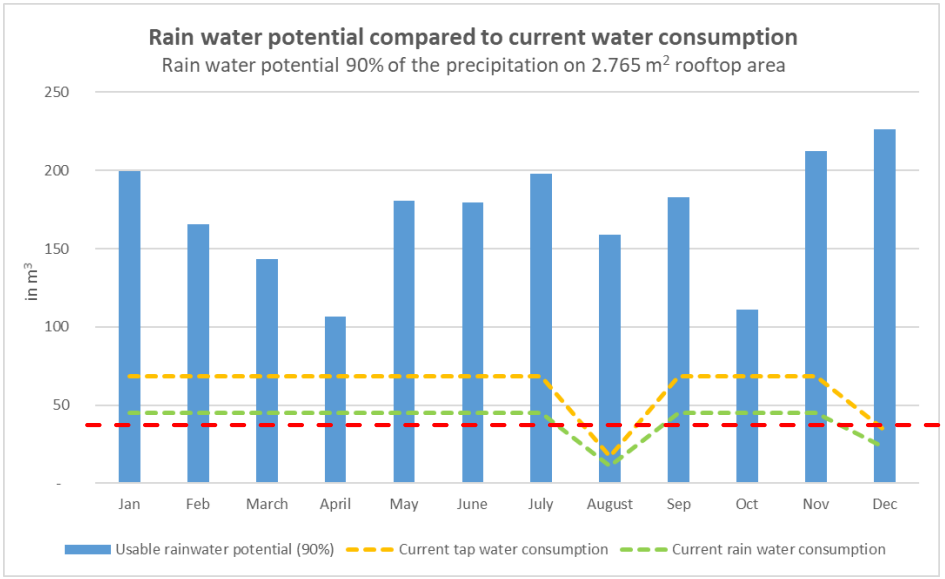
- Building Integrated Photovoltaics (balustrade & shading canteen):
  → Estimated installed capacity of 4,4 kWp
  → Estimated electricity production of 3.000 kWh/a
  e.g.: 50 - 75% of the greenhouse electricity can be covered (by using a battery)
- PV potential on other rooftops
  → 35 – 70 kWp are possible
  → Estimated electricity production of up to 31.000 - 63.000 kWh/a

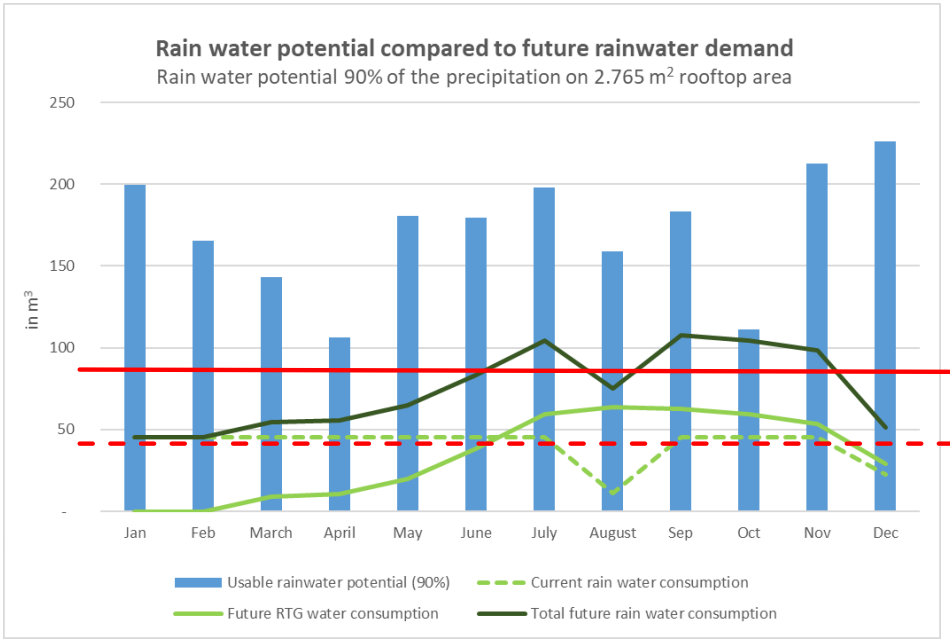




Source: Face InTec, 2020

Water consumption





DEMAND SUPPLY

Calculation according to:

- Local precipitation
- Potential to harvest the rainwater
- Calculation and differentiation between water users, type of water and temporal demand
- Additional water consumption of the greenhouse on temporal scale

- **RTG:** 100% rainwater usage
  - Depending on precipitation and temporal crop irrigation water requirements
  - Seasonality, storage options and water quality are challenges

→ **In soilless culture special attention to (homogenous) water quality is needed**

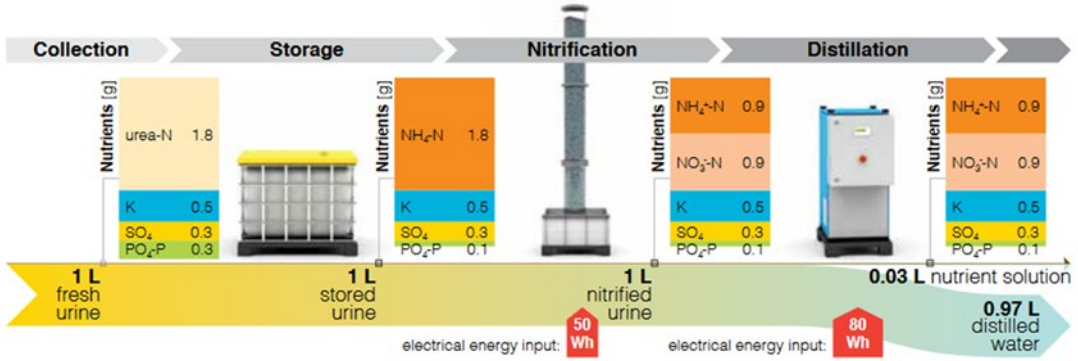
Potential analyse of area

Separation of urine from toilets through:

- suspended separation toilets
- separated collection of ww from urinals

Restrictions of the nutrient potential use:

- Only theoretical potential of nutrient demand and nutrient availability
- P & K directly plant-available
- N only partly plant available (as NO_3^- or NH_4^+)
- Higher requirements for soilless cultivation in greenhouse



Urine and fertilizer production potential

Example: 450 m² RTG (Tomato)

→ Theoretical total amount of approximately 25 m³ per year

→ Provides: 44 kg N; 2,7 kg P and 22 kg K on annual basis

→ 90% of the N could be covered

Source: U. Kirschnick, 2020

Source: Etter & Udert, 2016. VUNA Handbook on Urine; Viskari et al., 2018. Fertilizer potential of human urine in barley cultivation

Conclusion and GROOF experience

- **Building:**
  - **Industrial warehouses** is not a beneficial building type for RTG
  - In terms of **ventilated facades** a physical connection between RTG and building is impossible
  - A load capacity **> 400 kg/m²** of the rooftop is needed (depend on the RTG-type)
  - By a **redesign process of buildings or by the planning of new building** the highest amount of synergies between greenhouse and building can be exploited. (waste heat, urine collection, grey water and rainwater usage, CO2 usage from the ventilation system etc.)
  - **Promising building types:**
    Big residential buildings, office buildings, grocery / retail stores, data centre

- **Greenhouse**
  - **High energy efficiency** greenhouse,
  - **High area efficiency** (vertical farming, fertilization and workspace in the basement)
  - Future Opportunities: Greenhouse could be used as **solar collector** in the transition period

Conclusion and GROOF experience

- **Synergies:**
  - **Energy:**
    Waste heat usage from the building, waste heat from the greenhouse, insulation effects, renewable energies (PV-System),
  - **Water and fertilizer:**
    Rainwater collection, grey water usage, urine collection and treatment, CO_2 fertilization,
  - **Local food and social aspects:**
    A short food value chain, social activities, solidary agriculture, education concepts for rooftop farming

- **Stakeholders:**
  - A high communication work is needed to implement a greenhouse on rooftop
  - For the building owner a high administrative work is needed
  - The identification of greenhouse builder takes time
  - Coordination process are hart (Administration, Architect, Greenhouse builder etc.)

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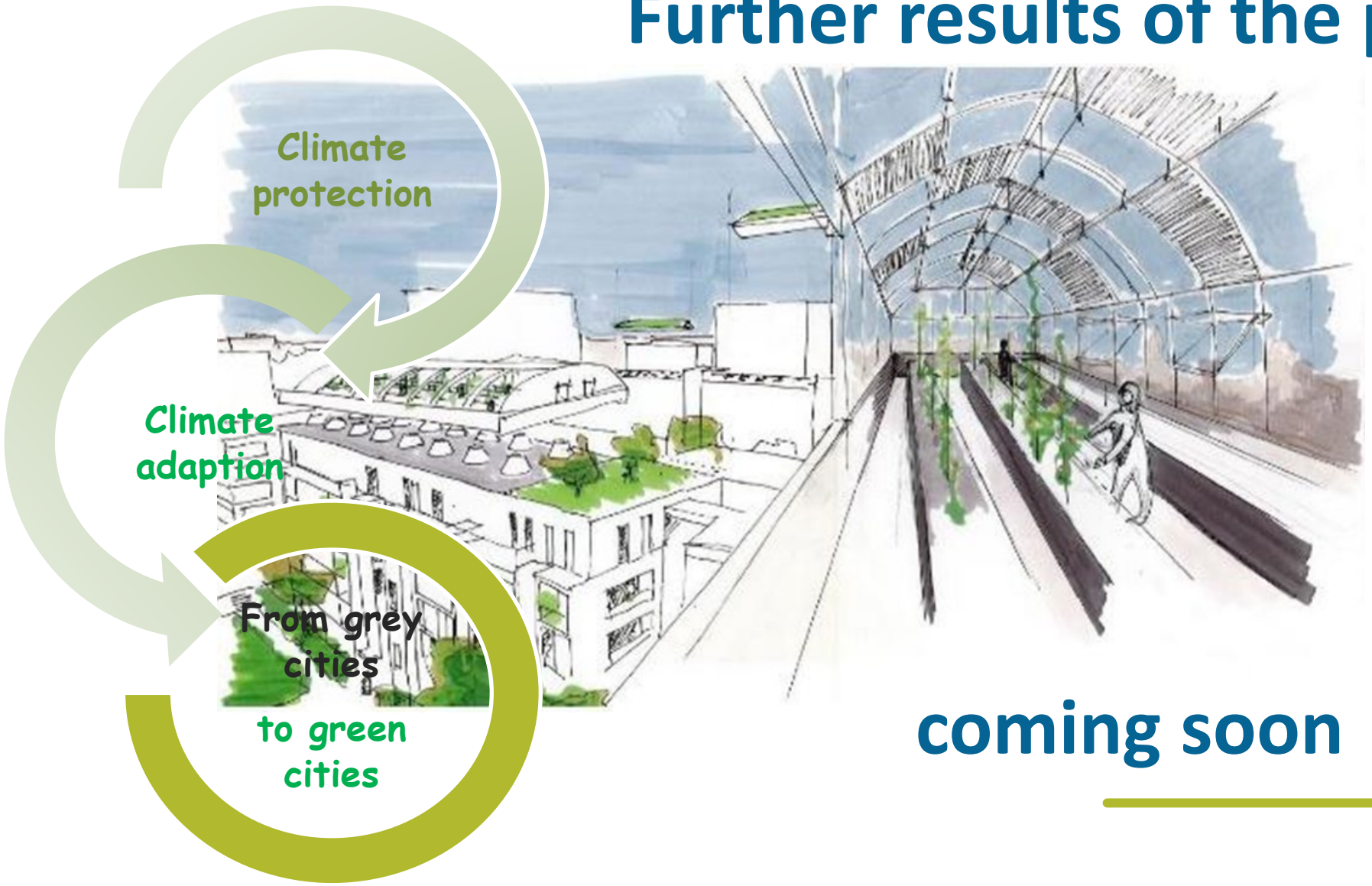
Further results of the project



coming soon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