Life cycle assessment of biomethane from wastewater algae

The All-Gas approach

Biorefineries

Microalgae session

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SEVENTH FRAMEWORK
PROGRAMME

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Content

- **The All-Gas project**
- Goal and scope of the life cycle assessment
- Results and discussion
- Conclusions

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»Industrial scale demonstration of sustainable algae cultures for biofuel production« – The All-Gas Approach

Objectives

- Large demonstration plant: Farming area 10 hectares
- Full industrial plant: from biomass production to fuel processing and fleet demonstration
- To use only carbon from non-fossil fuel sources for growth supplementation (CO_2 from biogas and biosolid combustion)
- To achieve yields > 90 t of algal biomass $ha^{-1}*yr.^{-1}$ $(25*g*m^{-2}*d^{-1})$
- To make use of the wastewater nutrients for algal growth

All-Gas Pilot Plant in Chiclana de la Frontera

- 10 ha open ponds supplied with pre-treated wastewater
- Production of biogas
  - by upflow anaerobic sludge blanket (UASB) and
  - by anaerobic digester
- Upgrading of biogas to biomethane as fuel

Photo of the All-Gas pilot plant

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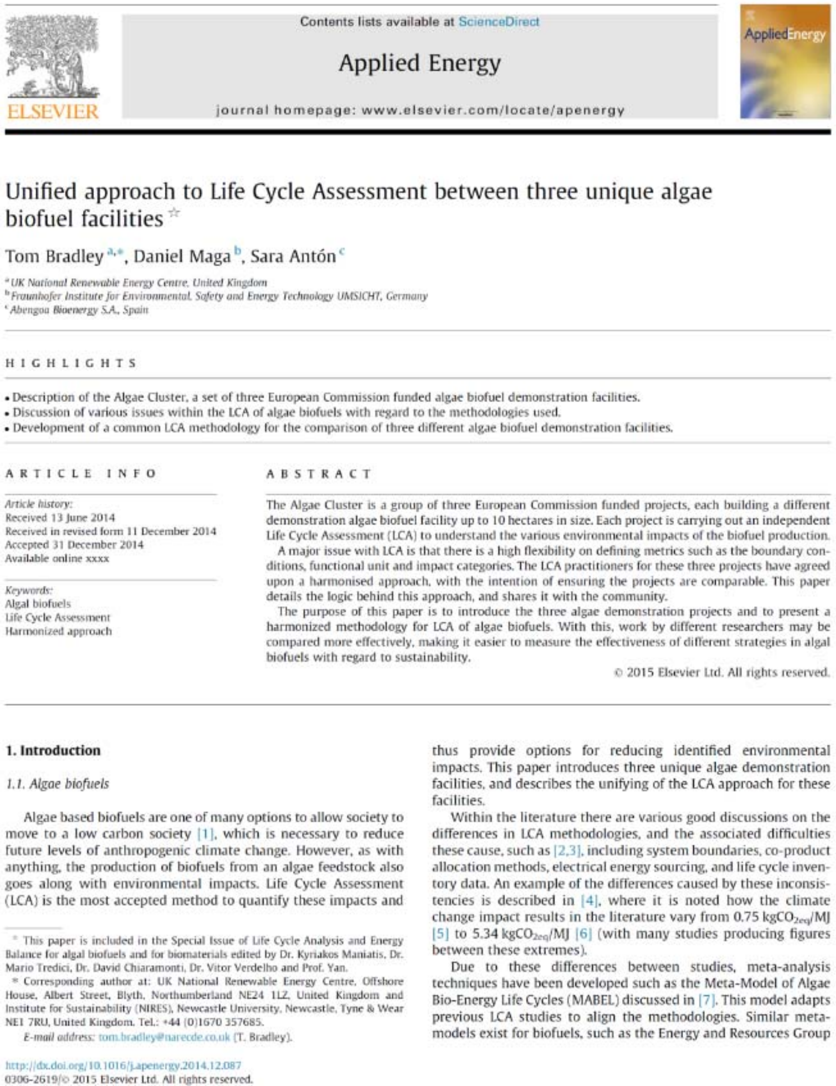
Life cycle assessment methodology

Common methodology of the Algae Cluster: http://www.algaecluster.eu/

3 case LCA studies

- All-Gas
- InteSusAl
- BIOFAT



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Unified approach to Life Cycle Assessment between three unique algae biofuel facilities ☆

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HIGHLIGHTS

- Description of the Algae Cluster, a set of three European Commission funded algae biofuel demonstration facilities.
- Discussion of various issues within the LCA of algae biofuels with regard to the methodologies used.
- Development of a common LCA methodology for the comparison of three different algae biofuel demonstration facilities.

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ABSTRACT

The Algae Cluster is a group of three European Commission funded projects, each building a different demonstration algae biofuel facility up to 10 hectares in size. Each project is carrying out an independent Life Cycle Assessment (LCA) to understand the various environmental impacts of the biofuel production.

A major issue with LCA is that there is a high flexibility on defining metrics such as the boundary conditions, functional unit and impact categories. The LCA practitioners for these three projects have agreed upon a harmonised approach, with the intention of ensuring the projects are comparable. This paper details the logic behind this approach, and shares it with the community.

The purpose of this paper is to introduce the three algae demonstration projects and to present a harmonized methodology for LCA of algae biofuels. With this, work by different researchers may be compared more effectively, making it easier to measure the effectiveness of different strategies in algal biofuels with regard to sustainability.

1. Introduction

1.1. Algae biofuels

Algae based biofuels are one of many options to allow society to move to a low carbon society [1], which is necessary to reduce future levels of anthropogenic climate change. However, as with anything, the production of biofuels from an algae feedstock also goes along with environmental impacts. Life Cycle Assessment (LCA) is the most accepted method to quantify these impacts and thus provide options for reducing identified environmental impacts. This paper introduces three unique algae demonstration facilities, and describes the unifying of the LCA approach for these facilities.

Within the literature there are various good discussions on the differences in LCA methodologies, and the associated difficulties these cause, such as [2,3], including system boundaries, co-product allocation methods, electrical energy sourcing, and life cycle inventory data. An example of the differences caused by these inconsistencies is described in [4], where it is noted how the climate change impact results in the literature vary from 0.75 $kgCO_{2eq}/MJ$ [5] to 5.34 $kgCO_{2eq}/MJ$ [6] (with many studies producing figures between these extremes).

Due to these differences between studies, meta-analysis techniques have been developed such as the Meta-Model of Algae Bio-Energy Life Cycles (MABEL) discussed in [7]. This model adapts previous LCA studies to align the methodologies. Similar meta-models exist for biofuels, such as the Energy and Resources Group

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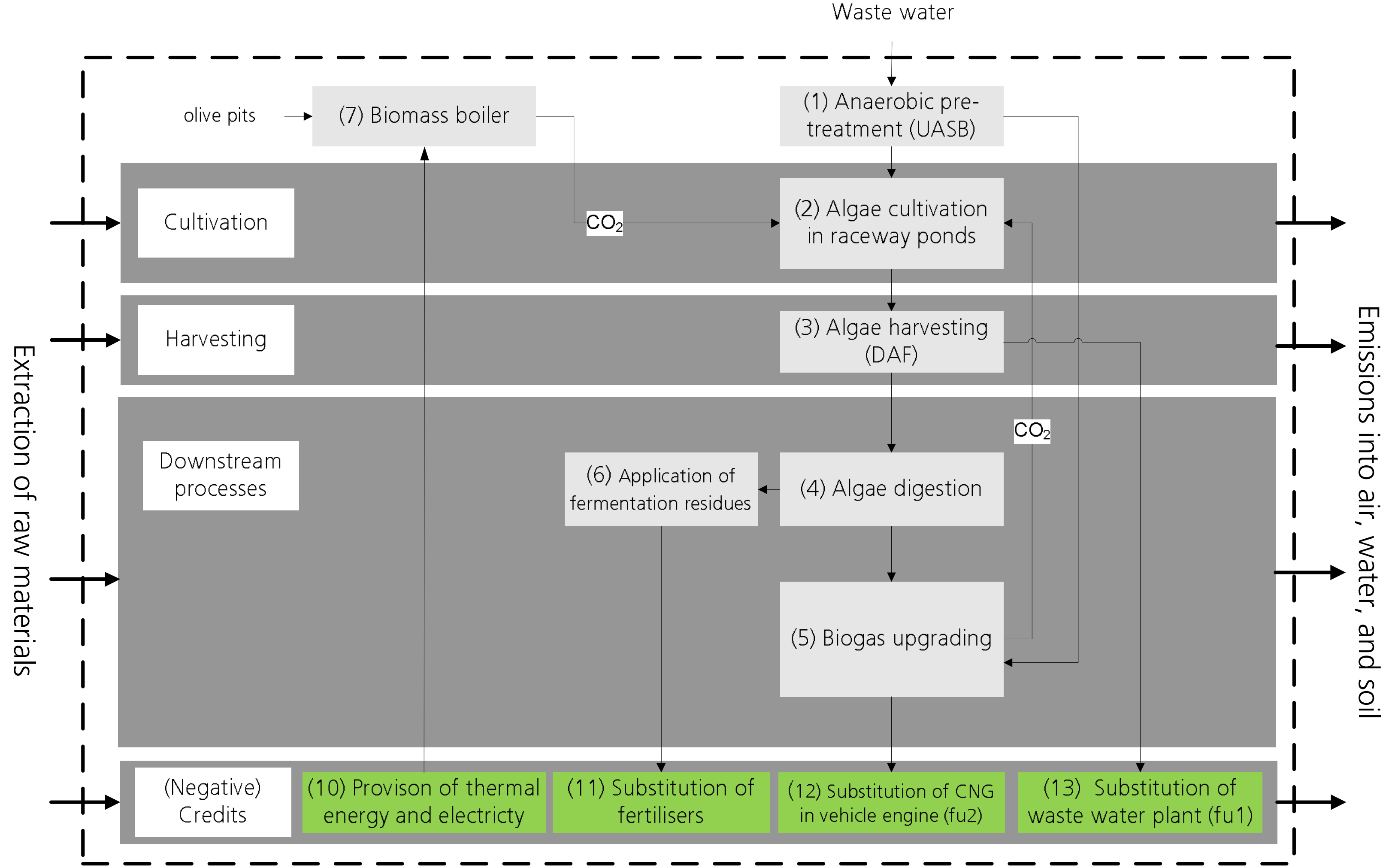
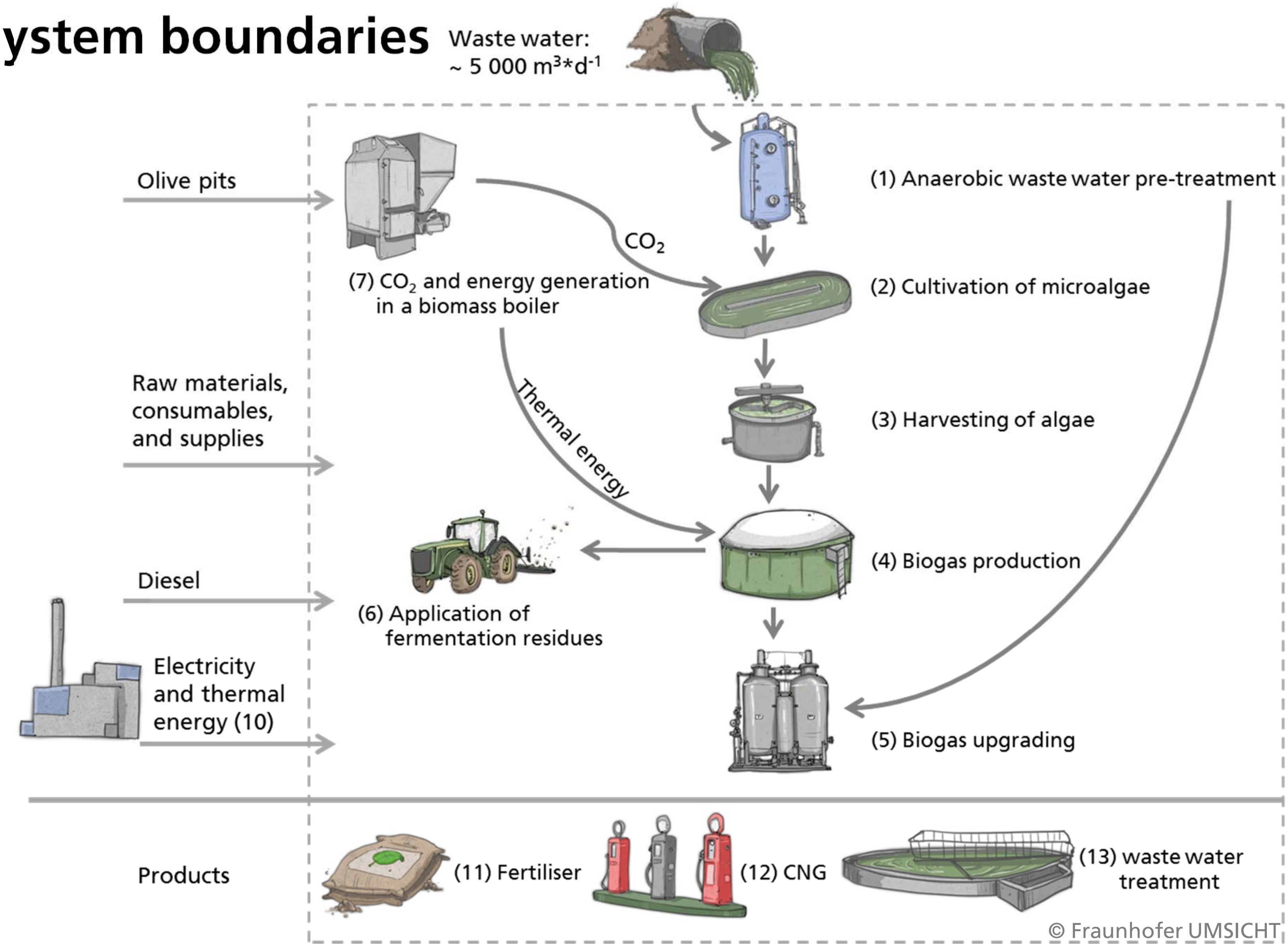
System boundaries and functional unit



Functional units (FU): FU1: 1 m^3 of treated waste water,
FU2: 1 MJ fuel in car engine

System boundaries



Waste water:
~ 5 000 $m^3 * d^{-1}$

Olive pits

Raw materials,
consumables,
and supplies

Diesel

Electricity
and thermal
energy (10)

(1) Anaerobic waste water pre-treatment

(2) Cultivation of microalgae

(3) Harvesting of algae

(4) Biogas production

(5) Biogas upgrading

(6) Application of
fermentation residues

(7) CO_2 and energy generation
in a biomass boiler

CO_2

Thermal energy

Products

(11) Fertiliser

(12) CNG

(13) waste water
treatment

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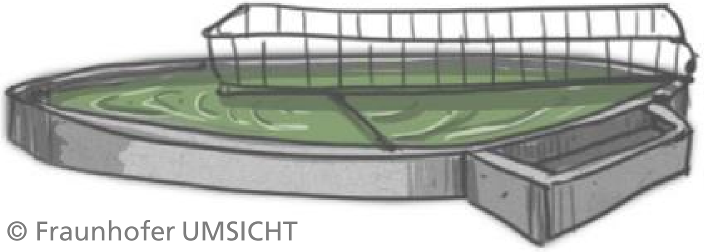
Reference system: Conventional waste water treatment

- European average waste water treatment plant (10 000 - 50 000 per-capita-equivalents)
  - Anaerobic digestion of prim. and sec. sludge
  - 100 % anaerobic sludge to incineration
- Today, in small cities in Spain oxidation ditches are installed that perform worse
  - Higher electricity consumption
  - Sewage sludge to field
  - Higher nitrous oxide emissions



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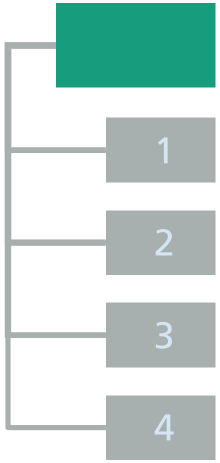
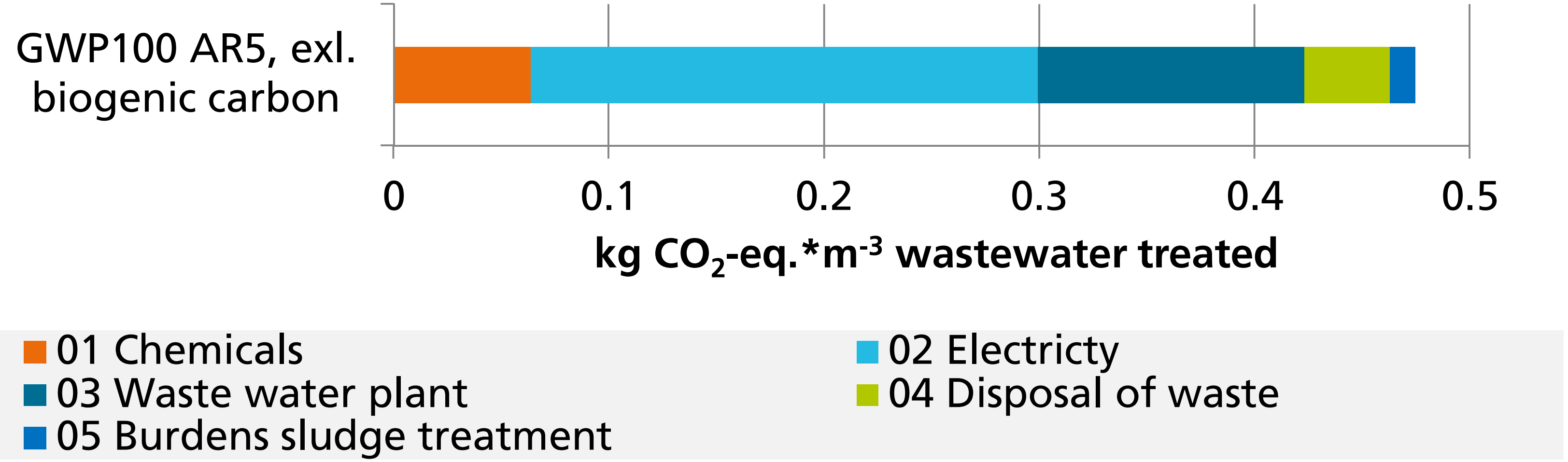


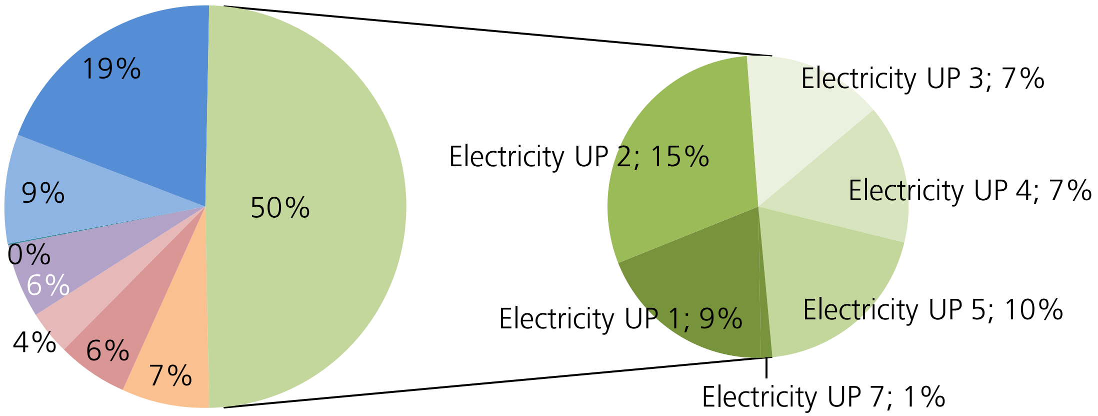
Carbon Footprint of reference waste water treatment

- 0.47 kg CO_2-eq.*m^{-3} of treated wastewater



- Main greenhouse gas (GHG) emissions can be traced back to the electricity demand of the WWT plant
  - total: 0.60 kWh*m^{-3}
  - net 0.49 kWh*m^{-3}

All-Gas: Distribution of primary energy demand (CED)



Total CED: 33 188 MJ*d^{-1}

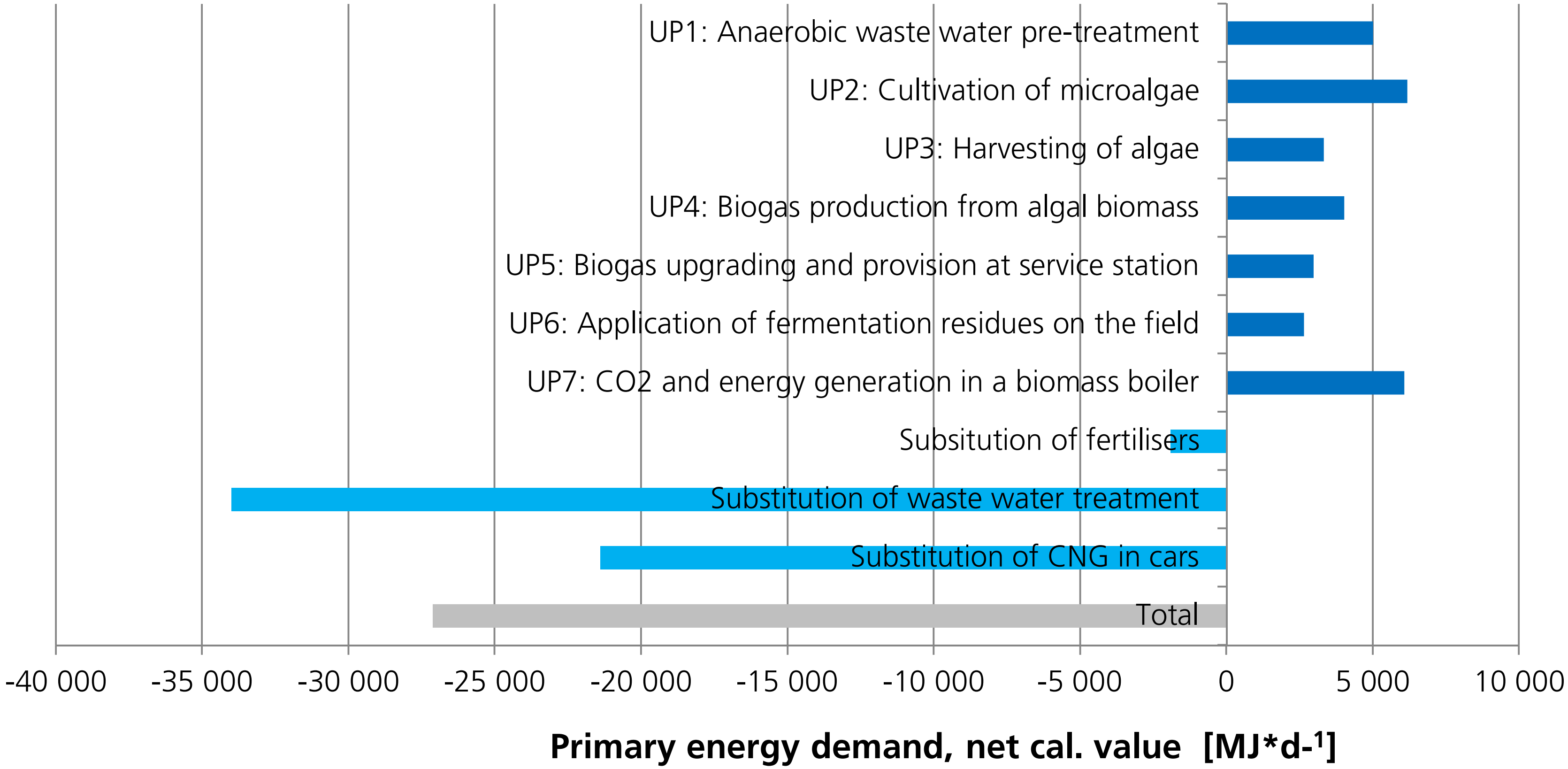
🟩 CED caused by electricity generation (green)

Indirect primary energy demand

- ■ UP1: Anaerobic waste water pre-treatment
- ■ UP2: Cultivation of microalgae
- ■ UP3: Harvesting of algae
- ■ UP4: Biogas production from algal biomass
- ■ UP5: Biogas upgrading and provision at service station
- ■ UP6: Application of fermentation residues on the field
- ■ UP7: CO2 and energy generation in a biomass boiler

- Approx. 50 % of CED can be traced back to the electricity

Energy balance of All-Gas (10 ha, 5 000 m^3*d^{-1})



- Credits for waste water treatment, fermentation residues, and compressed natural gas (CNG) in cars allow primary energy savings of approx. 27 000 $MJ*d^{-1}$

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Does the system provide more usable energy than it consumes? - Energy Return On Investment (EROI)

- EROI: Relation of primary energy supplied to primary energy used in supply process

$$EROI_{BM} = \frac{EC_{BM} + EC_{CP}}{E_{BM}} = \frac{LHV_{BM} * \rho_{BM} + EC_{CP}}{E_{BM}} = 1.9$$

EC_{BM}: energy content of biomethane

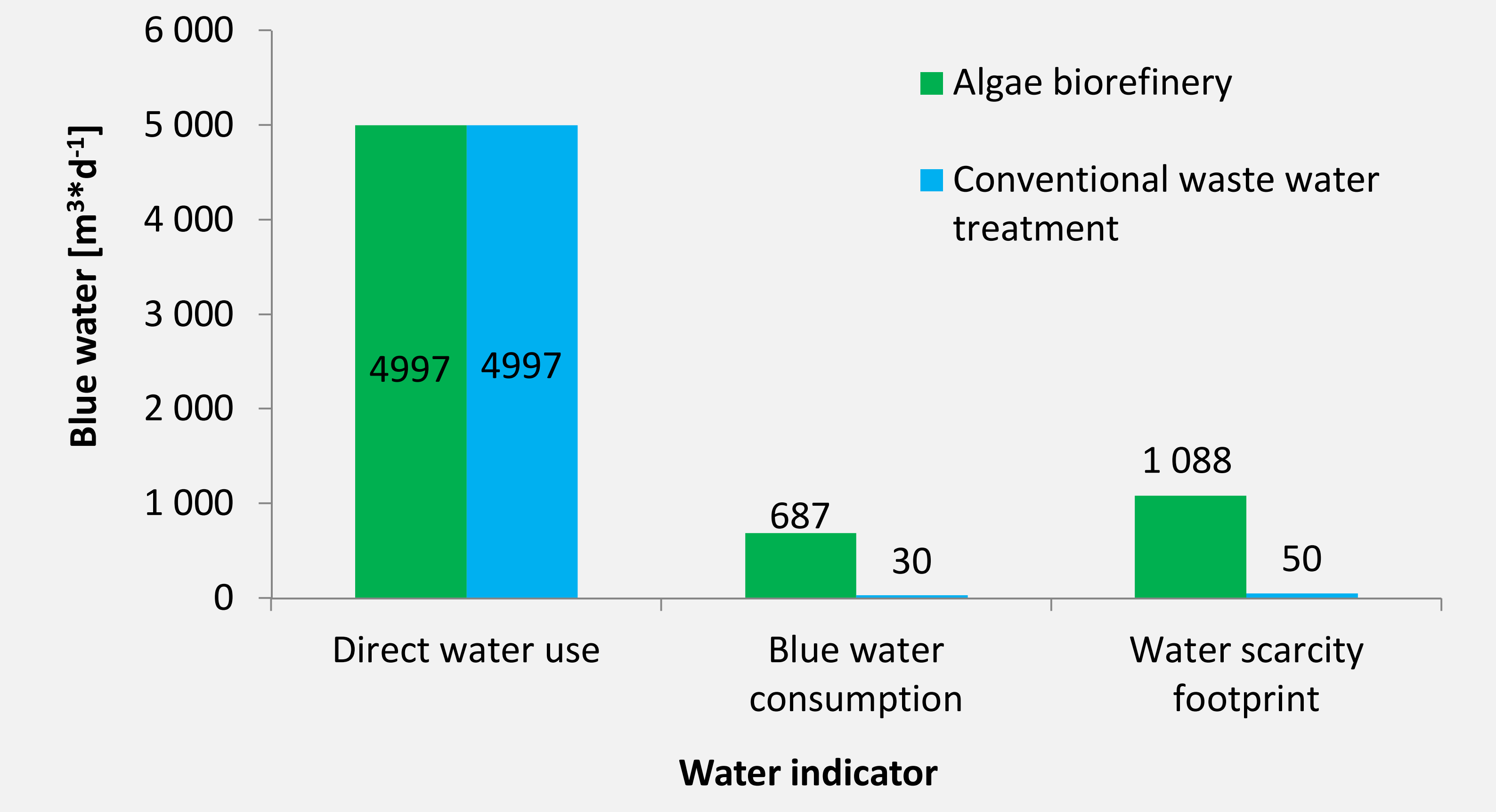
EC_{CP}: is the primary energy of the co-products fertilizer and water purification

E_{BM}: direct and indirect energy required to produce biomethane

→ The system produces two times more usable energy than it consumes

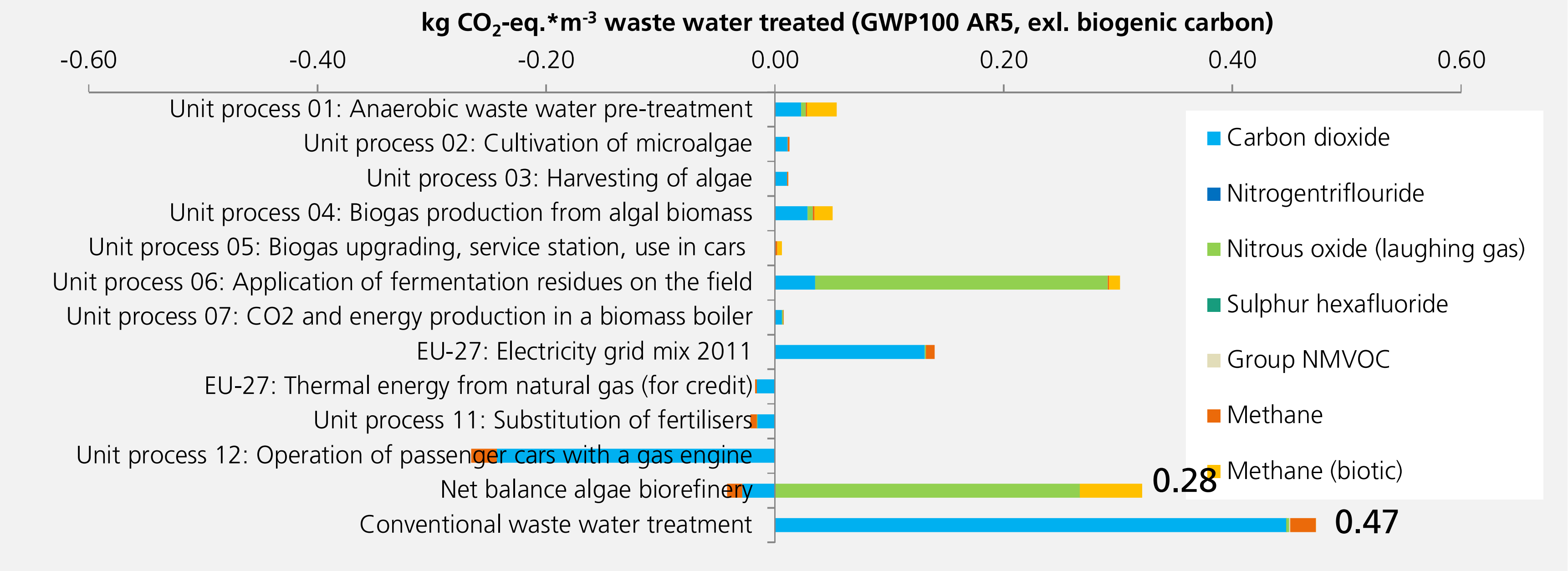
Water footprint

Water use, water consumption, and water scarcity footprint



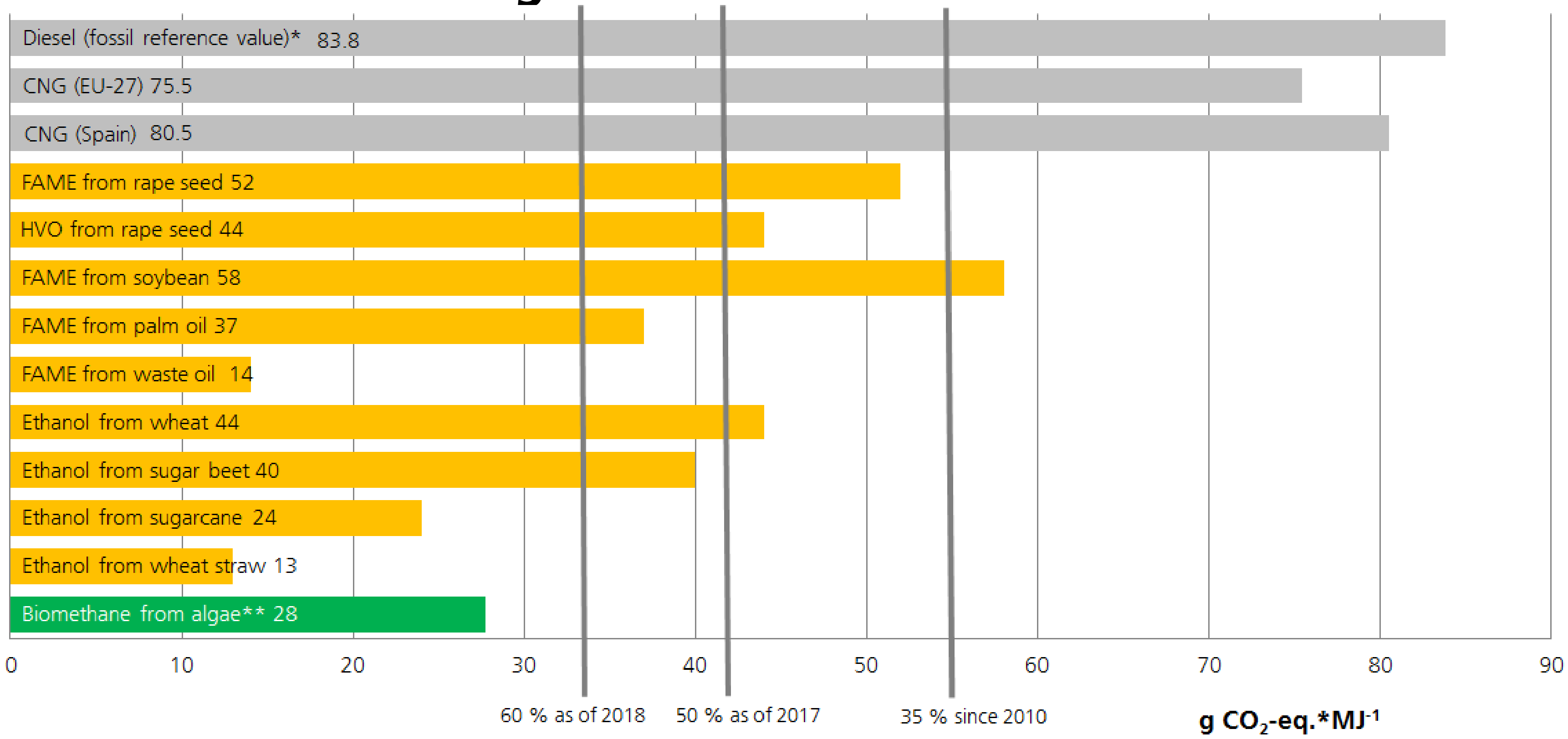
- Algae biorefinery has a higher water scarcity footprint
- But in both cases treated waste water might go to the sea

Does the All-Gas approach contribute to climate protection? Carbon Footprint of 1 m^3 treated waste water



- All-Gas approach allows approx. 40 % GHG savings compared to conventional waste water treatment
- N_2O strongly influences the GHG balance (application of fermentation residues on the field)

Comparison of green house gas (GHG) emissions of biomethane from algae to other fuels



* EU standard value (RED annex V); fossil reference value refers to diesel

** Biomethane from algae biorefinery: credits are given for waste water purification and for the application of fermentation residues on the field, GWP100: IPCC (2007)

- Biomethane from algae allows GHG savings of more than 60 %
- Different calculation approach (system expansion)!

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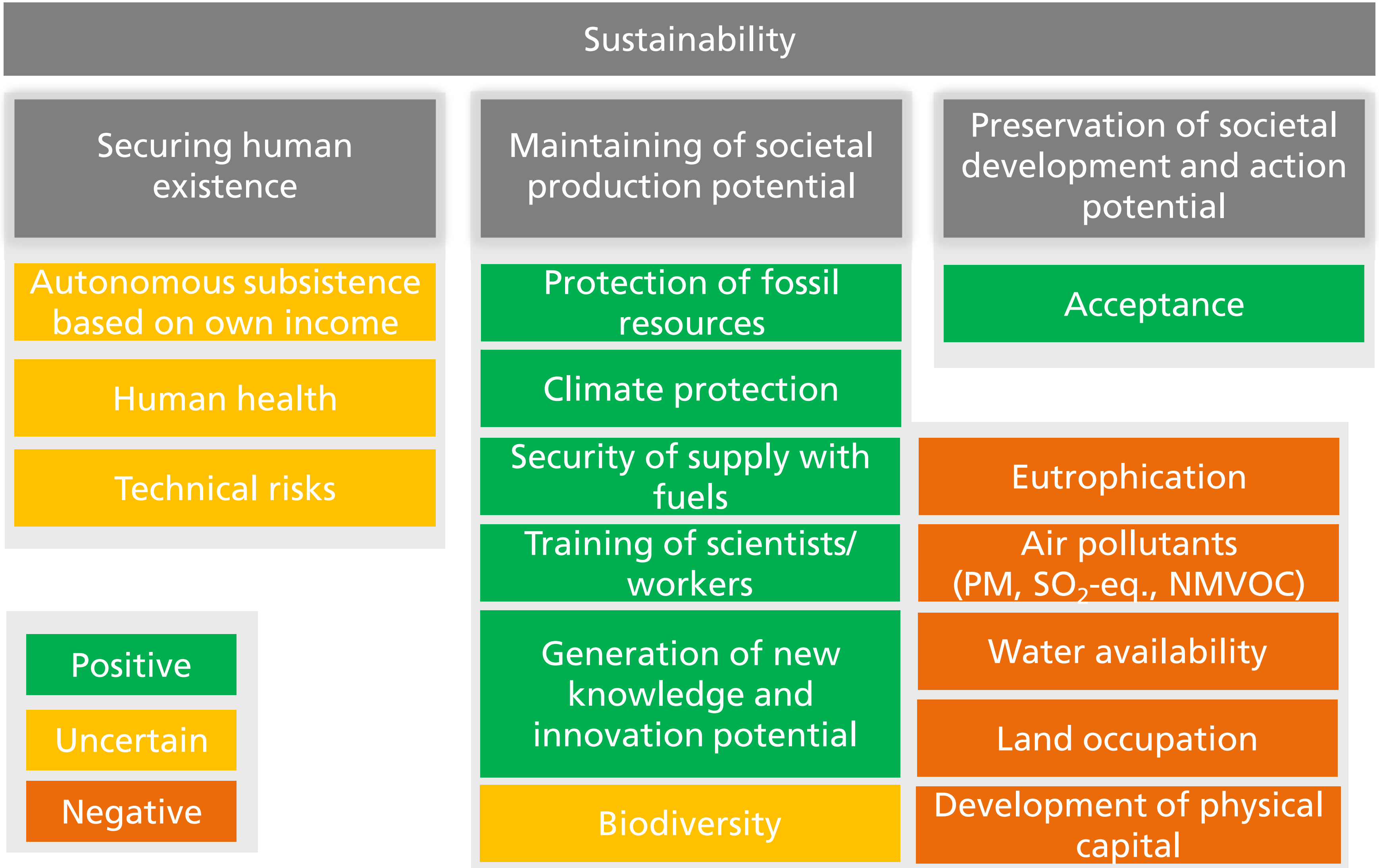
Summary of potential impacts of the algae biorefinery



Sustainability

Securing human existence
- 🟨 Autonomous subsistence based on own income
- 🟨 Human health
- 🟨 Technical risks

Maintaining of societal production potential
- 🟩 Protection of fossil resources
- 🟩 Climate protection
- 🟩 Security of supply with fuels
- 🟩 Training of scientists/ workers
- 🟩 Generation of new knowledge and innovation potential
- 🟨 Biodiversity

Preservation of societal development and action potential
- 🟩 Acceptance

- 🟧 Eutrophication
- 🟧 Air pollutants (PM, SO_2-eq., NMVOC)
- 🟧 Water availability
- 🟧 Land occupation
- 🟧 Development of physical capital

🟩 Positive
🟨 Uncertain
🟧 Negative

Final conclusions

- Demonstration plant is still under development
- Algae biorefinery has already now proved to be an attractive alternative to conventional waste water treatment
- The approach allows the expansion of biofuels and contributes to the conservation of fossil energy carriers and to climate protection
- Environmental friendly management of fermentation residues (nutrients) is needed → high potential to further improve the overall performance
- Future products from algae might have a positive influence, too

PhD Thesis

- Entire sustainability assessment was published in the PhD thesis
- Will be available at the homepage of the University of Bochum and in Fraunhofer Publica: http://publica.fraunhofer.de/dokumente/N-364431.html
- ISBN: 978-3-87468-355-7

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Daniel Maga

A methodology to assess the contribution of biorefineries to a sustainable bio-based economy

Verlag Karl Maria Laufen

Contact

All-gas

Industrial scale demonstration of sustainable algae cultures for biofuel production

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Thanks for your attention!

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