Presentation based on:
Skrydstrup J, Larsen SL, Rygaard M. Eco-efficiency of water and wastewater management in food production: A case study from a large dairy in Denmark. *J Ind Ecol*. 2020;24:1101–1112. https://doi.org/10.1111/jiec.13011

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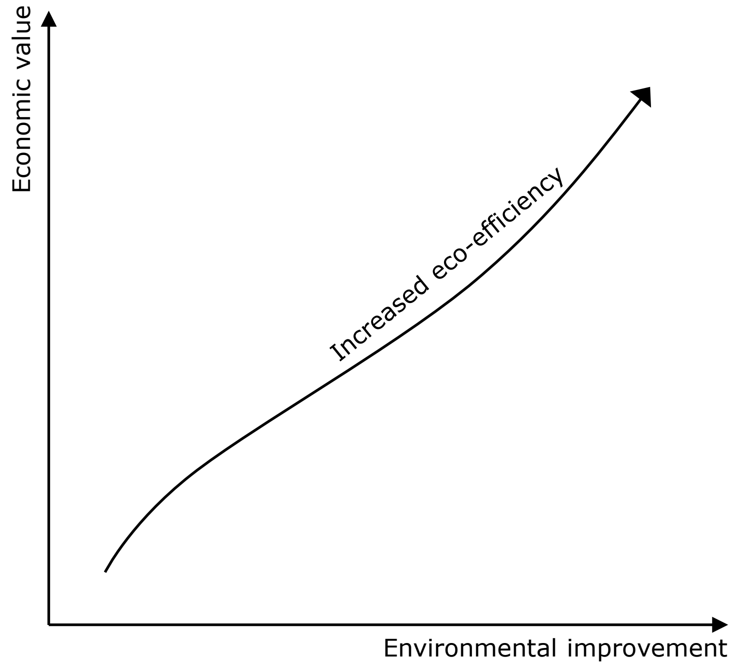
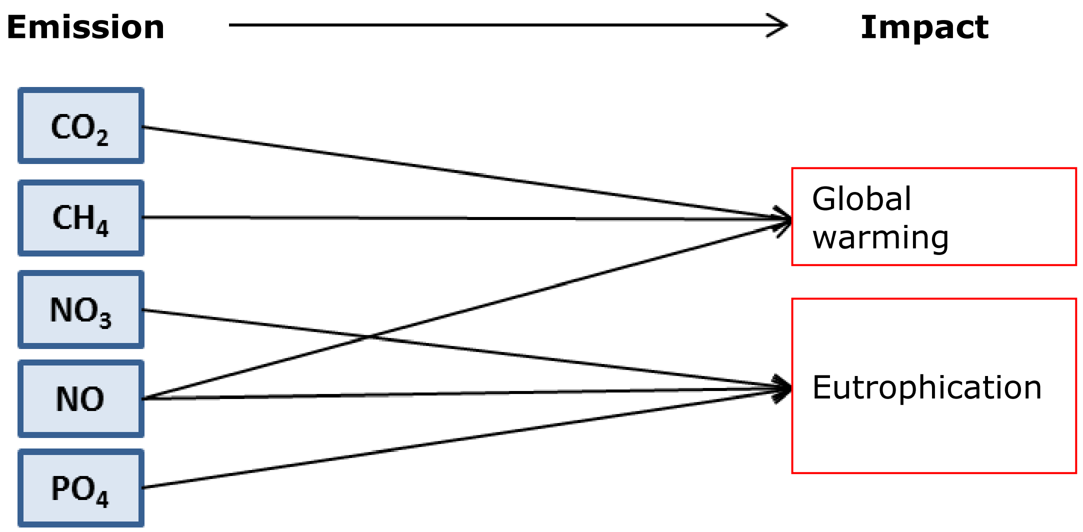
Eco-efficiency assessment of dairy wastewater reuse

Objective

1) to develop a method for eco-efficiency assessment consistent with established concepts of *value added* and *life-cycle assessment*
2) to demonstrate the eco-efficiency potential of a decentralized wastewater reuse facility in the HOCO dairy, Denmark



Environmental Life-Cycle Impact Assessment including Freshwater Impact Assessment



Freshwater Impact

$$FWI = Q_g \cdot \frac{WU}{WR - EWR}$$

(Godskesen et al. 2013)

Following ILCD guideline using EASETECH Version 2 (Clavreul et al 2014)

Economic life cycle assessment - value added (VA)

$$\text{Value Added} = \sum_{k} UP_k \cdot Q_k - \left[\sum_{j} \left(UP_j \cdot Q_j\right) + \sum_{q} FC_q\right]$$

= value left for salary, new investments, savings

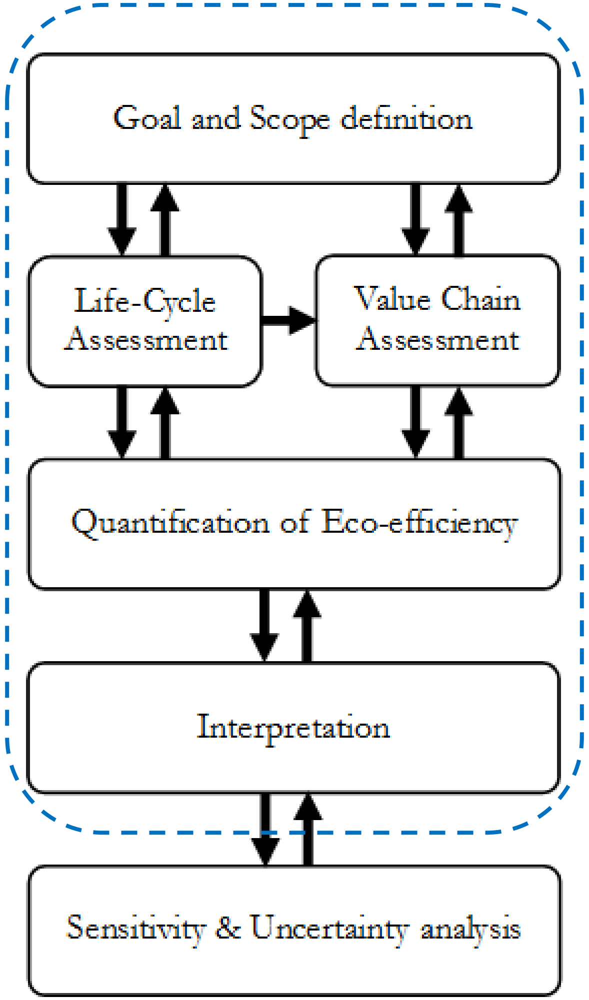
= value in societal terms

VA: Value Added [€/yr]

UP: Unit price

Q: Unit flow – material & energy

FC: Future Cash flow (e.g. re-investments



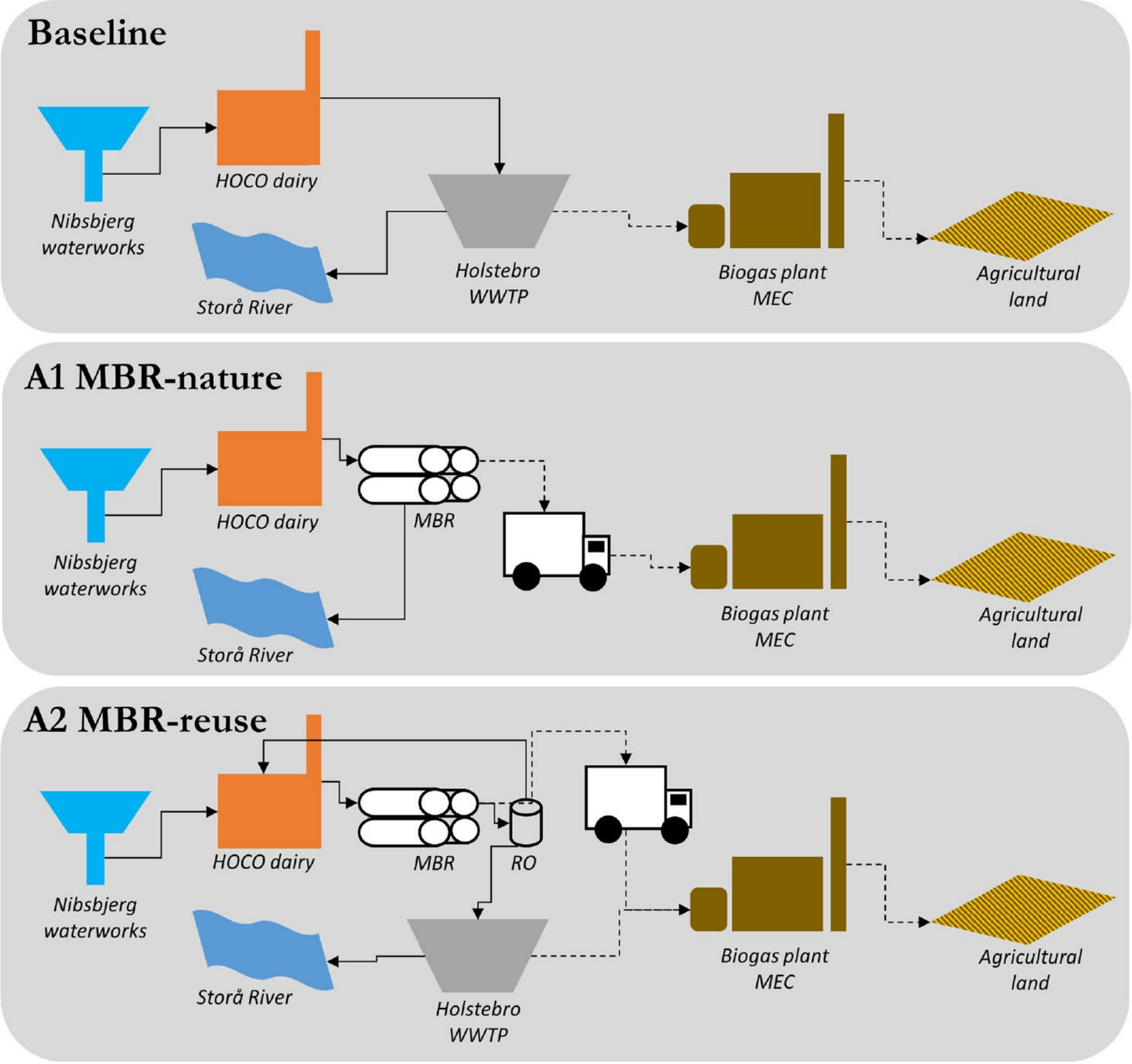
Modified from ISO 2012

Functional unit

“treatment of 1000 m^3 dairy wastewater”

All impacts expressed as changes compared to baseline

Cases and system boundaries



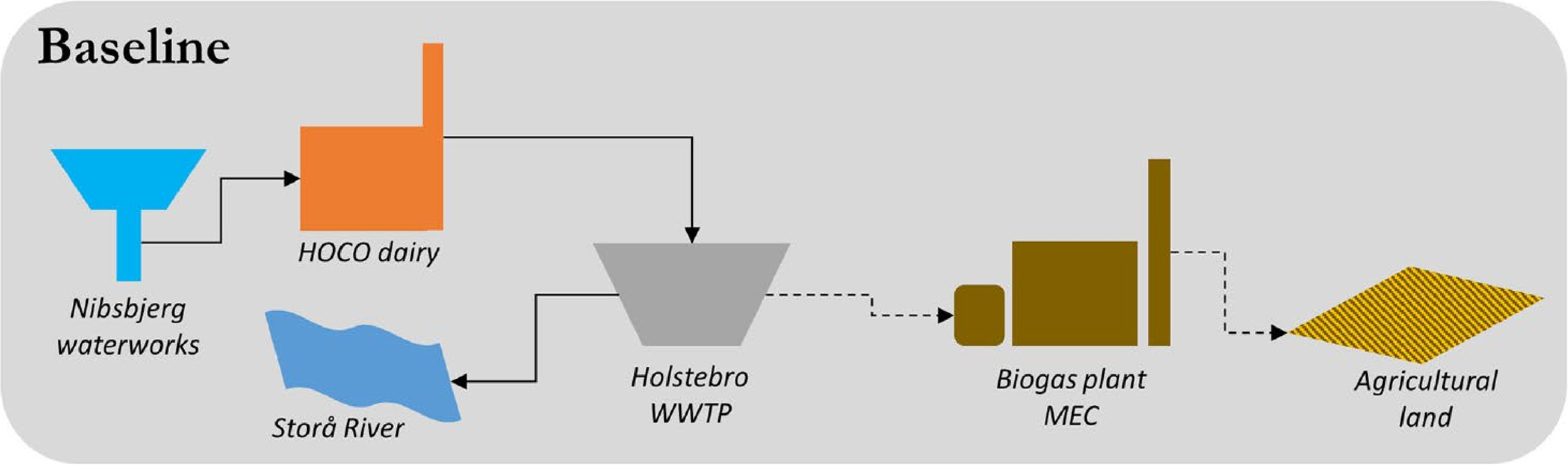
Annual flows:
530,000 tons raw milk

625,000 m^3 wastewater

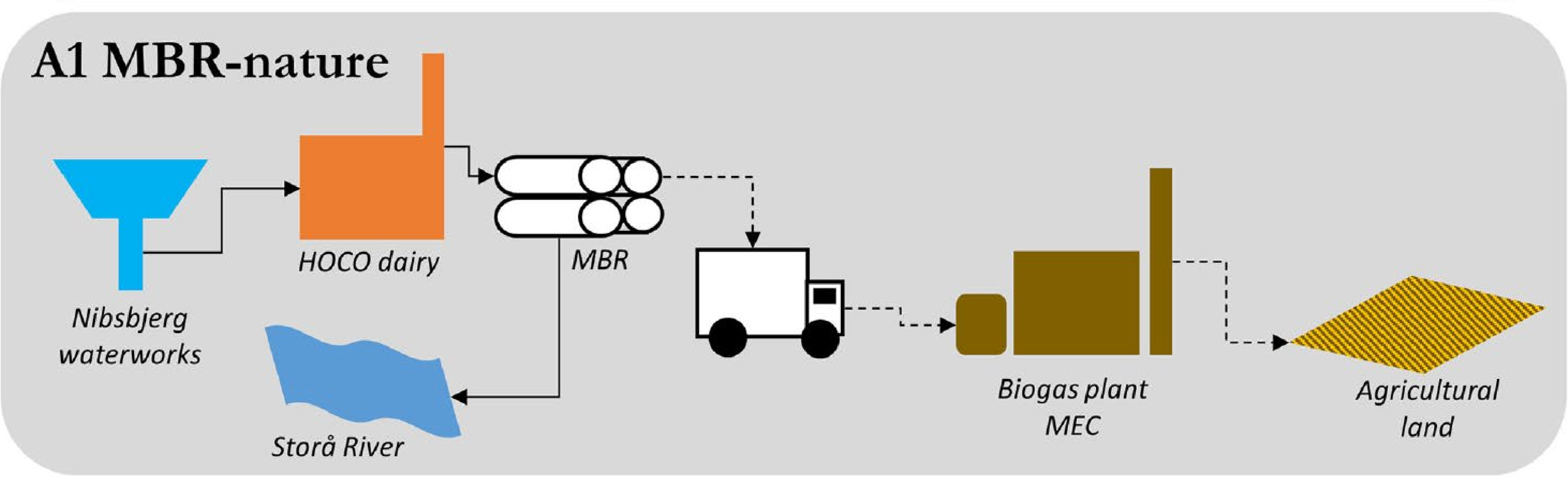
Comparative study:

Excluding processes affected less than 1%

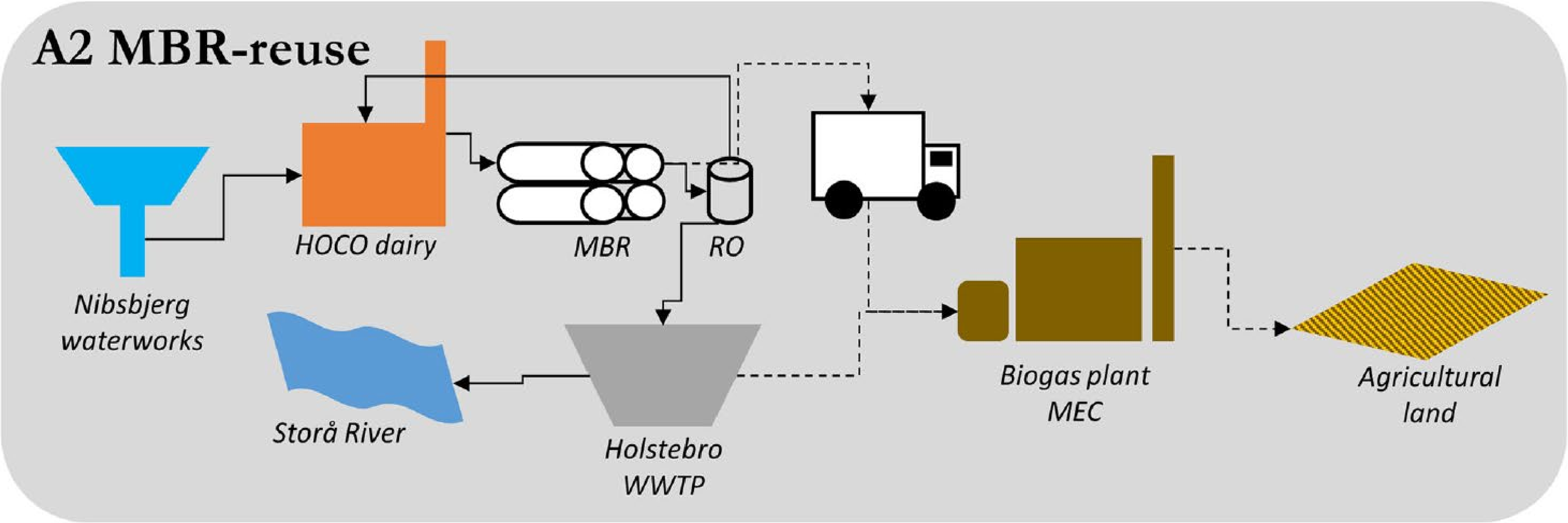
Cases and system boundaries



Cases and system boundaries



Cases and system boundaries



DTU

Data inventory

- System description
- Mass balances
- Exchanges with other systems
- Contribution and uncertainty

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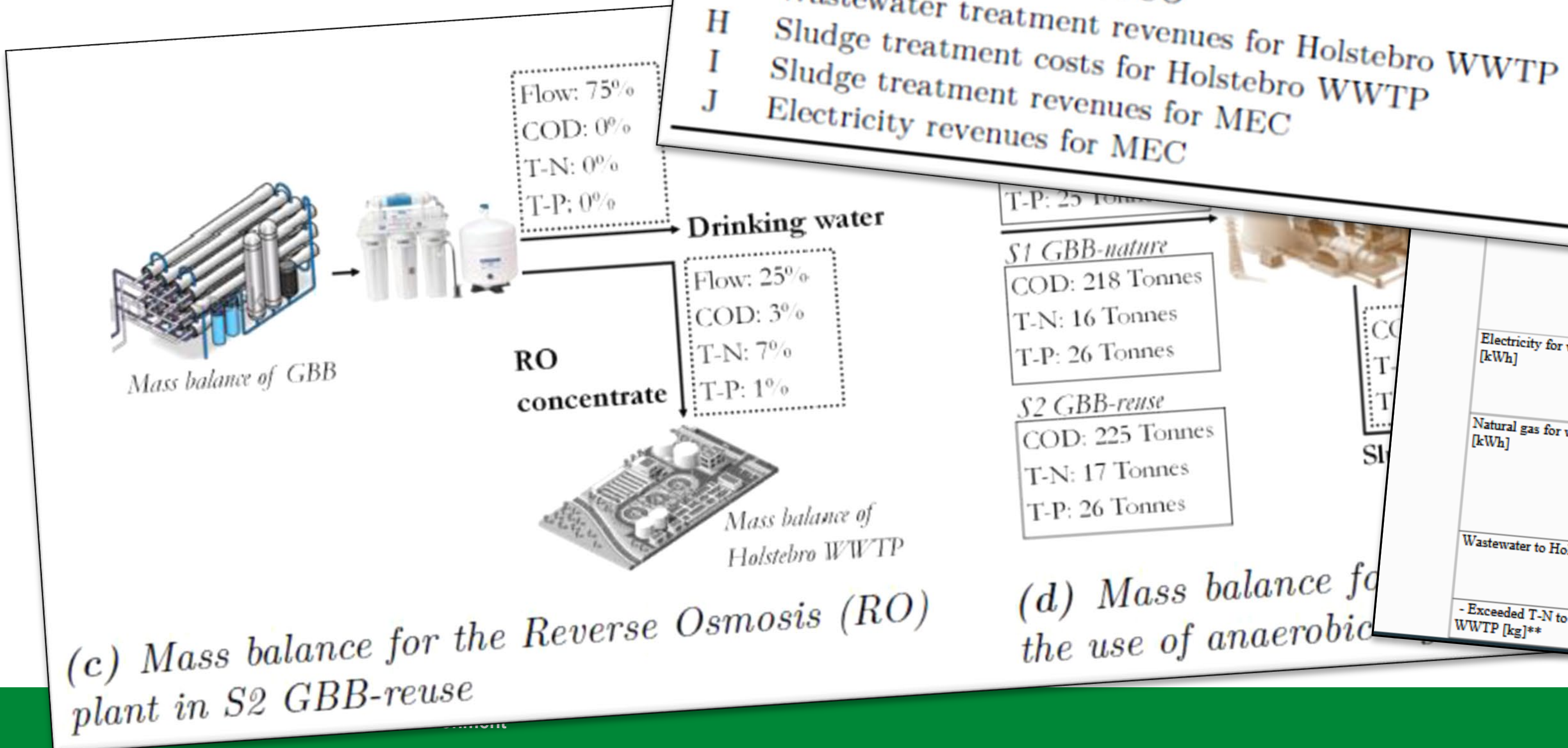
Table S5-1: Full inventory for the LCA and VCA

Parameters	Amount Baseline	A1	A2	Unit price [DKK/unit]	STD [%]***	Comments
Nibsjerg waterworks						
Groundwater abstraction [m³]*	937	937	132	-	10*	Groundwater are extracted from wells in the area. The amount is calculated by adding 7.1% (0.02% wastewater, 0.58% effluent and 6.2% loss to pipe network) water loss to HOCO's drinking water demand in 2015 (Nielsen, 2016). Estimated costs are included in the electricity consumption
Electricity consumption [kWh]	249	249	35	-0.2		Scaled from HOCO's total flows in 2015. Assumed linear relation between energy …
Electricity for water softening [kWh]	174	174	-	-0.2		… MBR, less acid is needed due to natural pH regulation by the bacteria. Unit price is estimated from a Swedish dairy factory where the MBR is already installed (Bhupendra, 2016). 1/4 of drinking water entering HOCO is softened. It is assumed that it is softened by RO, representing worst-case scenario. The RO consumes 0.8 kWh/m³ at a 10 degrees water temperature (Dalsgaard, 2016).
Natural gas for water heating [kWh]	28,603	28,603	20,431	-0.1	50*30**	40% of of the incoming drinking water are heated from approximately 10 to 80 degrees. The reused wastewater is 30 degrees, why less heat is required in the last scenario. It is assumed that the heat is supplied by natural gas, and the required quantity can be estimated by Q = W*cp*DeltaT.
Wastewater to Holstebro [m³]	1,000	-	249	-2.2	10**	Amount is based on HOCO's total wastewater in 2015 for the first scenario. The amount for the last scenario is calculated from the potential wastewater reuse.
- Exceeded T-N to Holstebro WWTP [kg]**	18	-	-	-0.6		In 2015 HOCO exceeded the maximum allowed amounts of T-N and T-P to Holstebro WWTP …

Table S7-2: Most contributing VCA parameters selected for sensitivity analysis for each scenario. B = Baseline, S1 = A1 MBR-nature, S2 = A2 MBR-reuse. Contribution is given as B/S1/S2. "-" means there is no contribution from that parameter

#	Parameter	Scenario	Contribution [%]
A	Drinking water revenues for Nibsjerg waterworks	B, S1	7/15
B	Wastewater treatment cost for HOCO	B, S2	43/22
C	Drinking water costs for HOCO	B, S1	10/23
D	Natural gas costs for HOCO	B, S1, S2	9/22/15
E	Electricity costs for HOCO	S1, S2	13/16
F	Investment costs for HOCO	S1, S2	11/12
G	Wastewater treatment revenues for Holstebro WWTP	B, S2	11/10
H	Sludge treatment costs for Holstebro WWTP	B, S2	4/2
I	Sludge treatment revenues for MEC	B, S2	11/5
J	Electricity revenues for MEC	S2	5



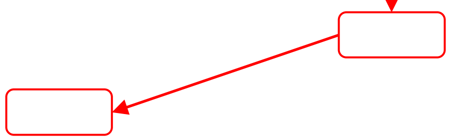
(c) Mass balance for the Reverse Osmosis (RO) plant in S2 GBB-reuse

(d) Mass balance fo… the use of anaerobic…

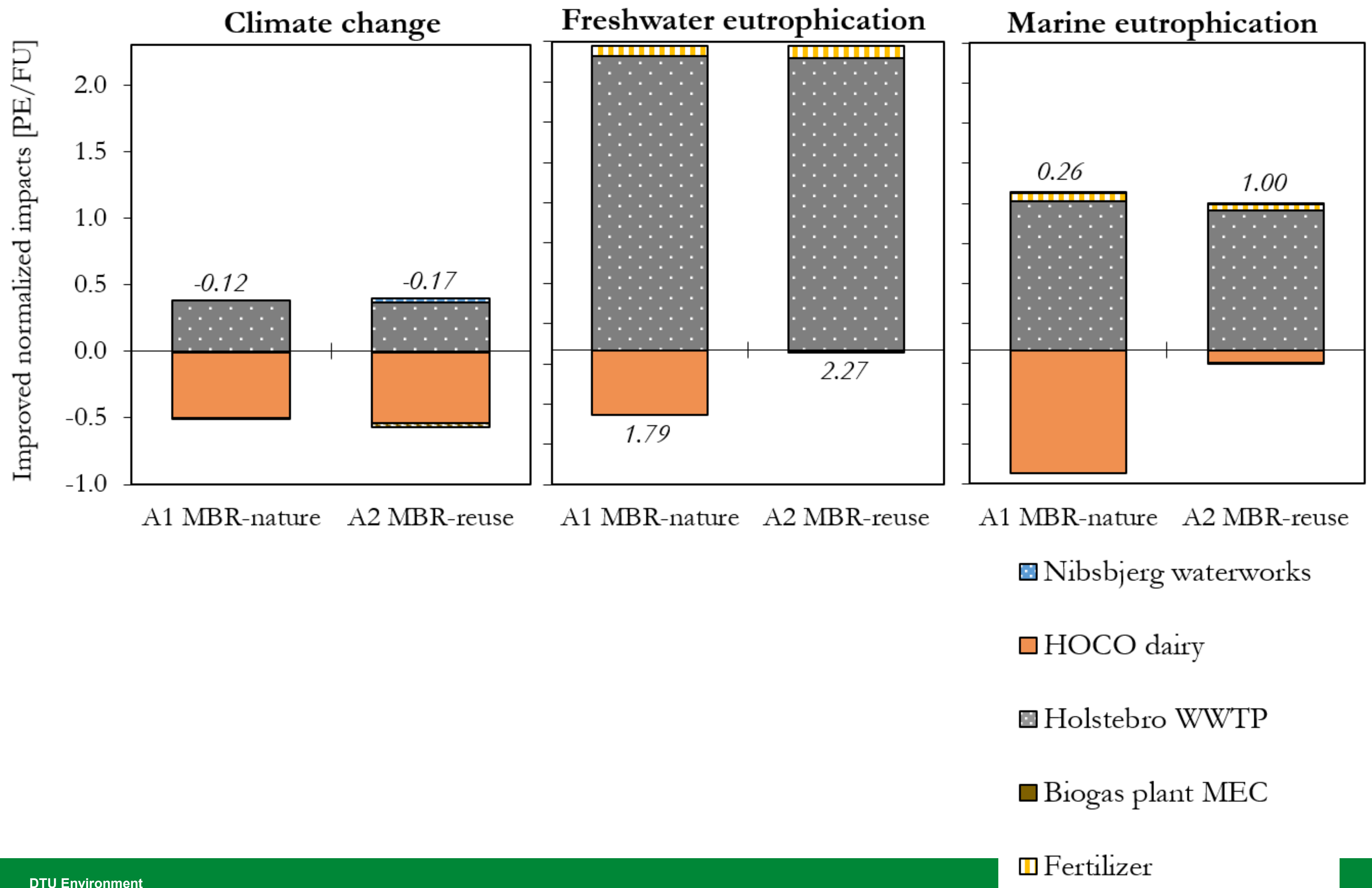
Results – inventory

Inventory per 1000 m³ wastewater

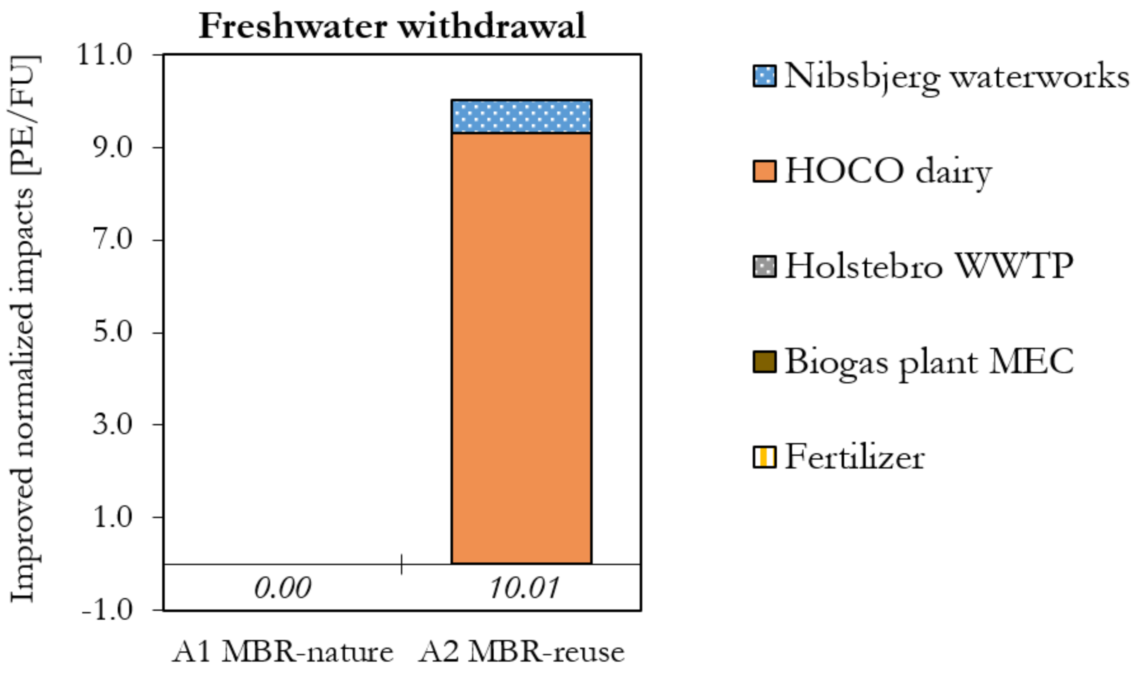
Case	Water works		Dairy				WWTP		Etc.
	Groundw. withdrawal (m³)	Electricity (kWh)	Drinking water (m³)	Electricity (kWh)	Wastewater (m³)	Methane to air (kg)	Electricity (kWh)	Methane to air (kg)	…
Baseline	937	249	871	-	1,000	-	1,064	75	…
MBR-Nature	937	249	871	1,705	-	83	-	-	…
MBR-Reuse	132	35	123	2,277	249	83	72	2	…



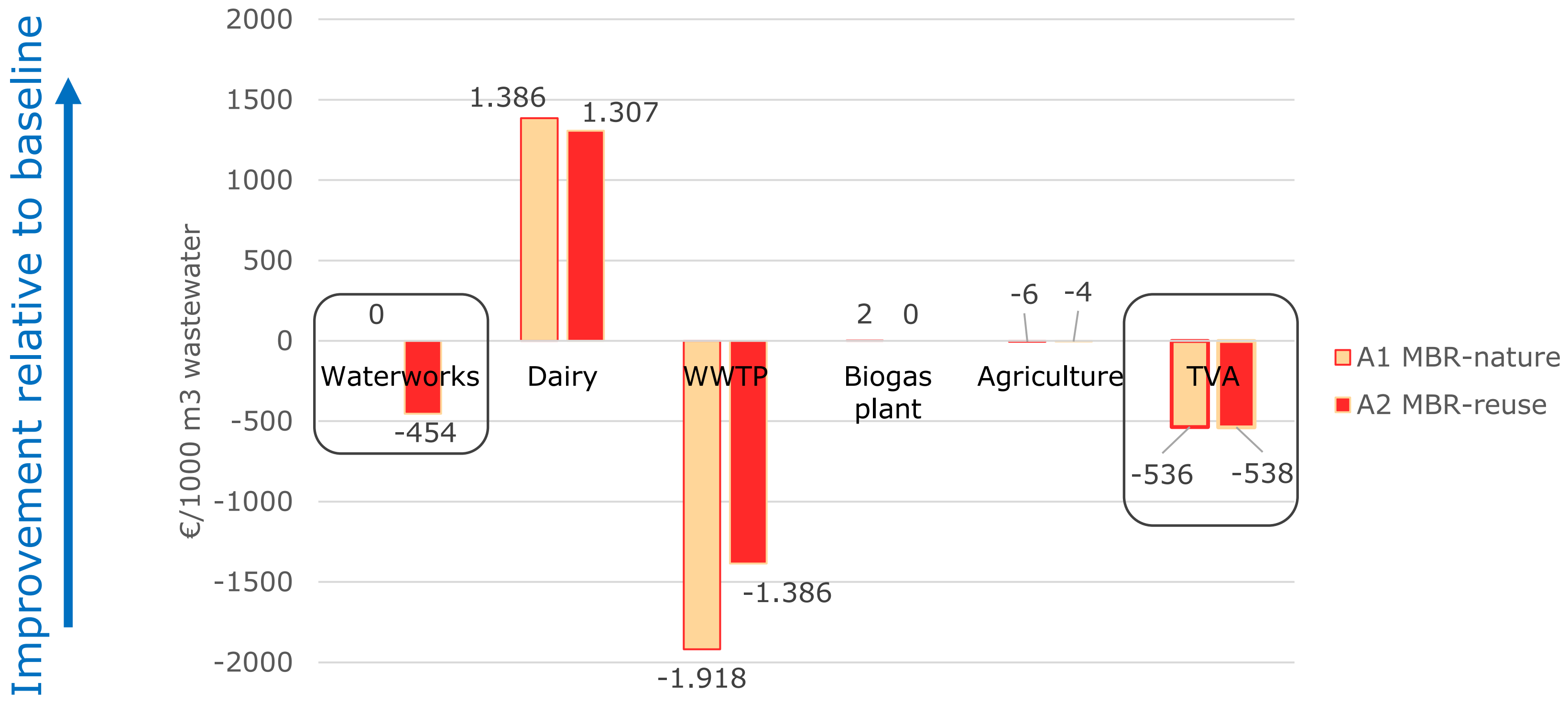
Results – key environmental impacts



Results – freshwater withdrawal



Results – Value added



Conclusions

The method

- Eco-efficiency documents value added and environmental impact along the value chain, for all actors
- Adds a societal perspective to the economic considerations
- Inform actors on dependencies and feedback mechanisms

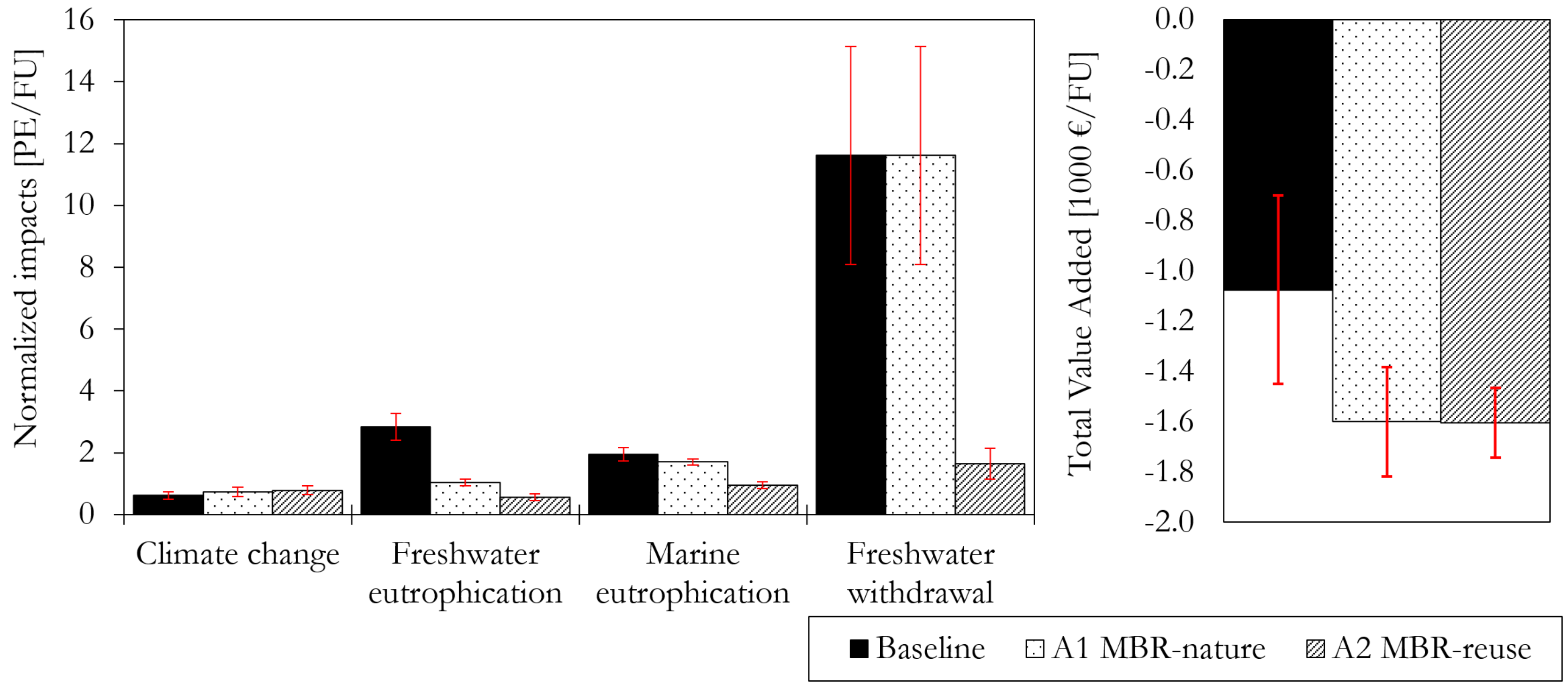
The dairy case

- For the dairy: Reuse of water adds value for the dairy, but reduces value along the value chain. Environmental impacts are generally reduced, except for global warming potentials

Things to study further

- Added value from expansion of production
- Impact of changing electricity production → renewables

Uncertainty – Monte Carlo



Thank you for your attention. Questions? mryg@env.dtu.dk

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