Advances in prospective LCIA: State-of-the-art and future directions

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Questions for Prospective Life Cycle Impact Assessment (LCIA)

1. Selection of impact categories	Is my impact category still relevant?
2. Assignment of LCI results	Are there new substances to be linked?
3. Characterization	Do characterization factors change?
4. Normalization	Which normalization reference?
5. Weighting	Which weighting?

Prospective LCIA considers future environmental conditions

- Atmospheric composition
- Oceanic pH
- Lake temperature
- Soil humidity
- Vegetation
- Distribution of skill color
- …

Pollutant

Release

T1 = 2015

Fate1
Exposure1
Effect1

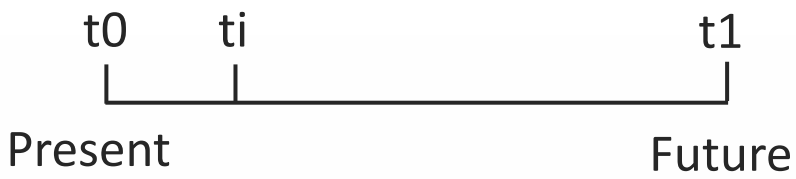
≠

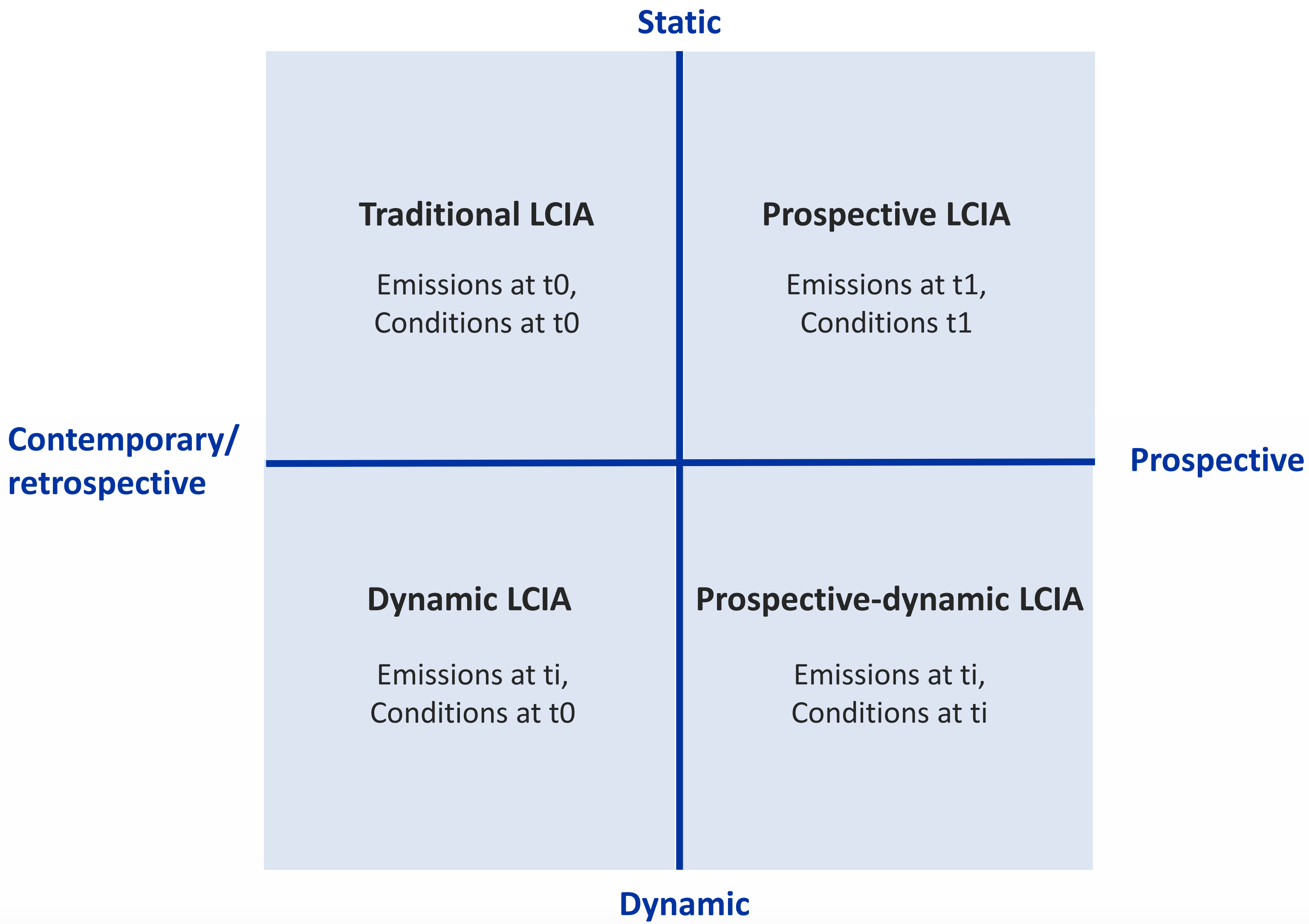
Release

T2 = 2050

Fate2
Exposure2
Effect2

Terminology





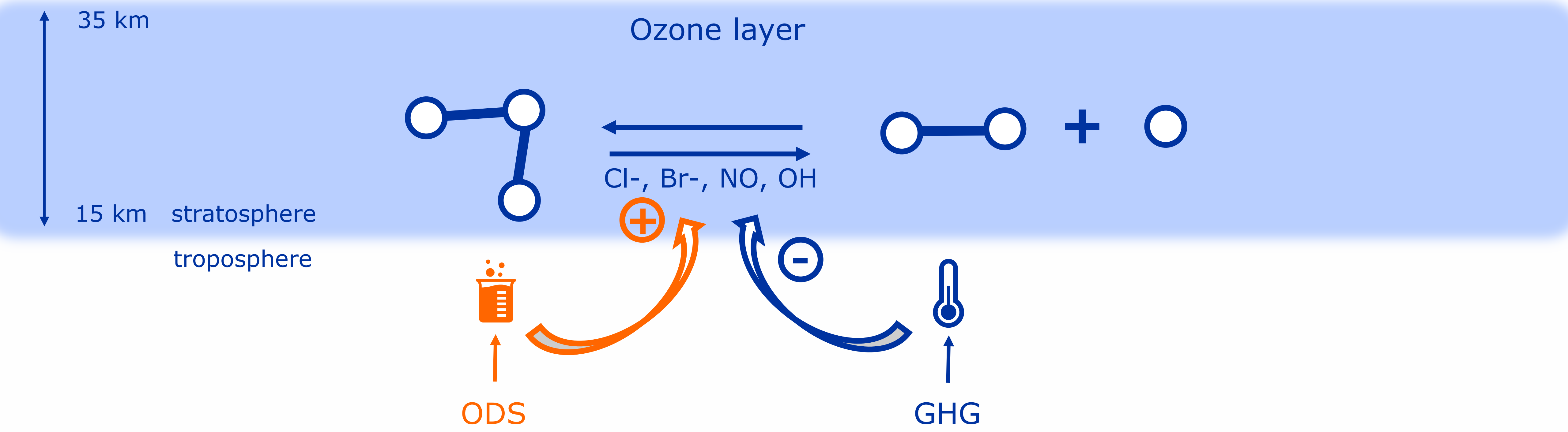
Introduction

Ozone depletion

SoA of other impact categories

Next steps

Stratospheric ozone science



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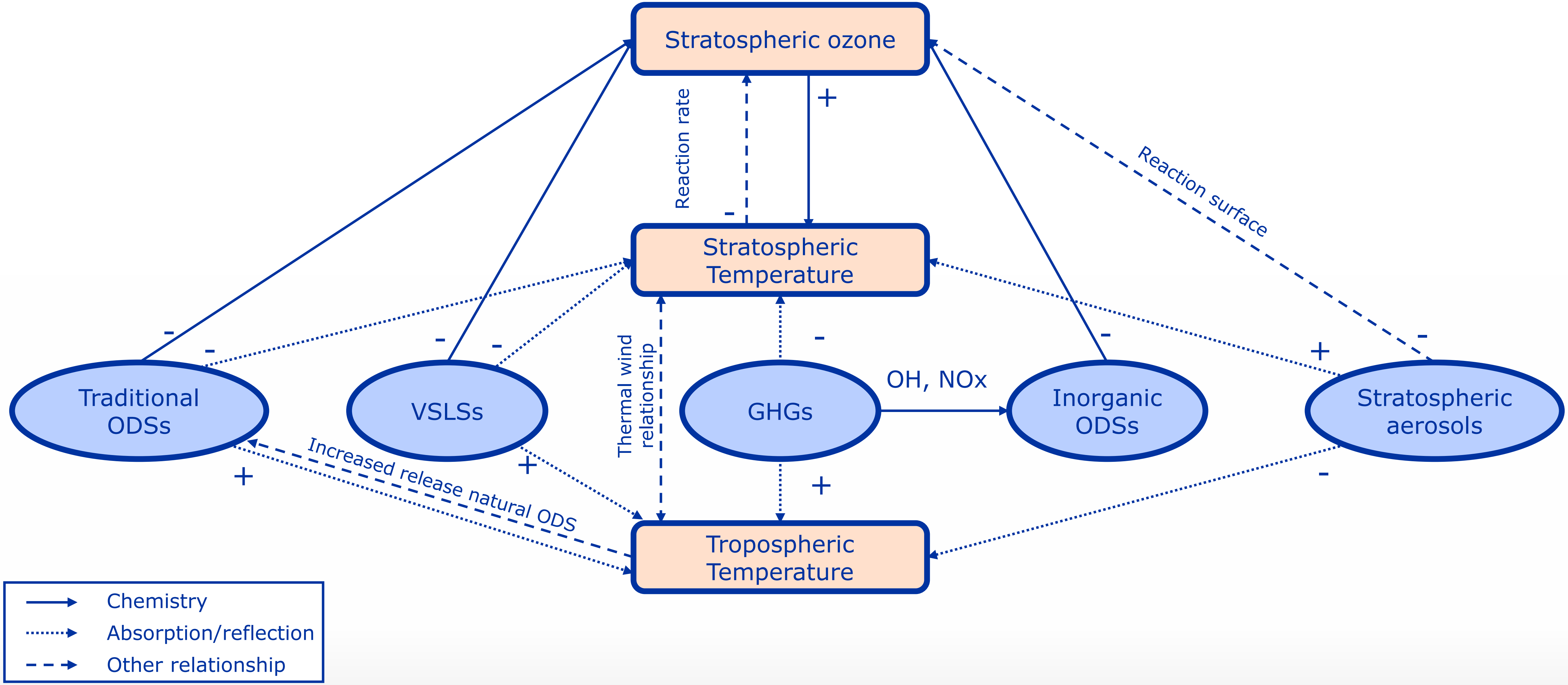
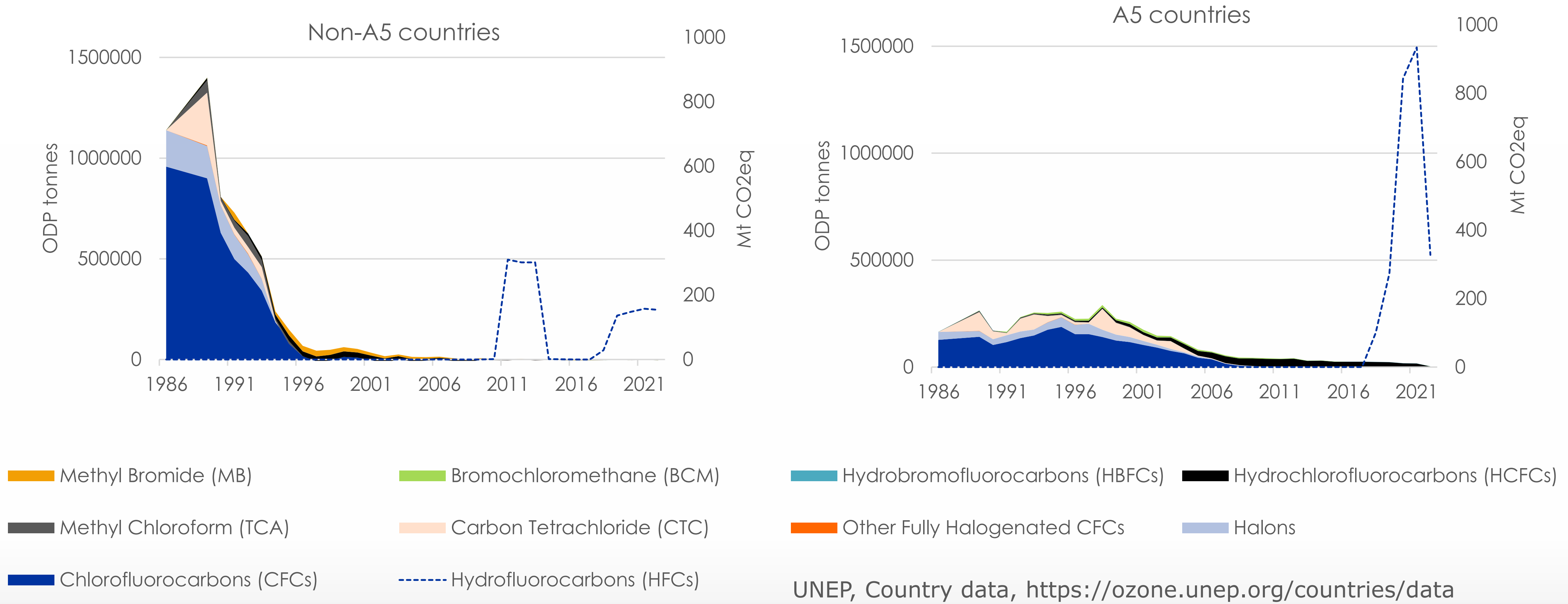


van den Oever et al., 2024, Revisiting the challenges of ozone depletion in life cycle assessment, Cleaner Environmental systems 13, 100196, https://doi.org/10.1016/j.cesys.2024.100196

Is it relevant to assess ozone depletion in 2050?



UNEP, Country data, https://ozone.unep.org/countries/data

Is it relevant to assess ozone depletion in 2050?

Arguments for:

- New threads may arise (e.g., increased rocket launches, geoengineering)
- While the risk of ozone layer depletion diminish, the potential impact is devastating on all life on earth

Counterarguments:

- Most ozone-depletion substances are already banned
- The ozone layer is expected to be restored by 2060

Are there new substances to be linked?

1. **Iodine-containing substances (e.g., CFI3 and CH3I)**
   - Candidates for replacing HFCs
   - Short-lived (~ days) but 150 times more effective than chlorine
   - Relevant in regions with short transport time to the stratosphere
2. **Other very short-lived substances (VSLSs)**
   - Contribution to stratospheric chlorine increased by 63% between 1993-2020
3. **N_2O**
   - Main anthropogenic ODS today
   - Already in some impact methods (ReCiPe 2016, Impact World 2.1), but not all!
4. **Stratospheric aerosols**
   - Limited studies and no characterization possible yet

Included in: van den Oever et al., 2024, Dataset with updated ozone depletion characterization factors for life cycle assessment, Data in Brief 57, 111103, https://doi.org/10.1016/j.dib.2024.111103

Need for further research on potential effects

Are characterization factors changing?

Change in boundary layer mixing ratio

Atmospheric lifetime

Molecular weight

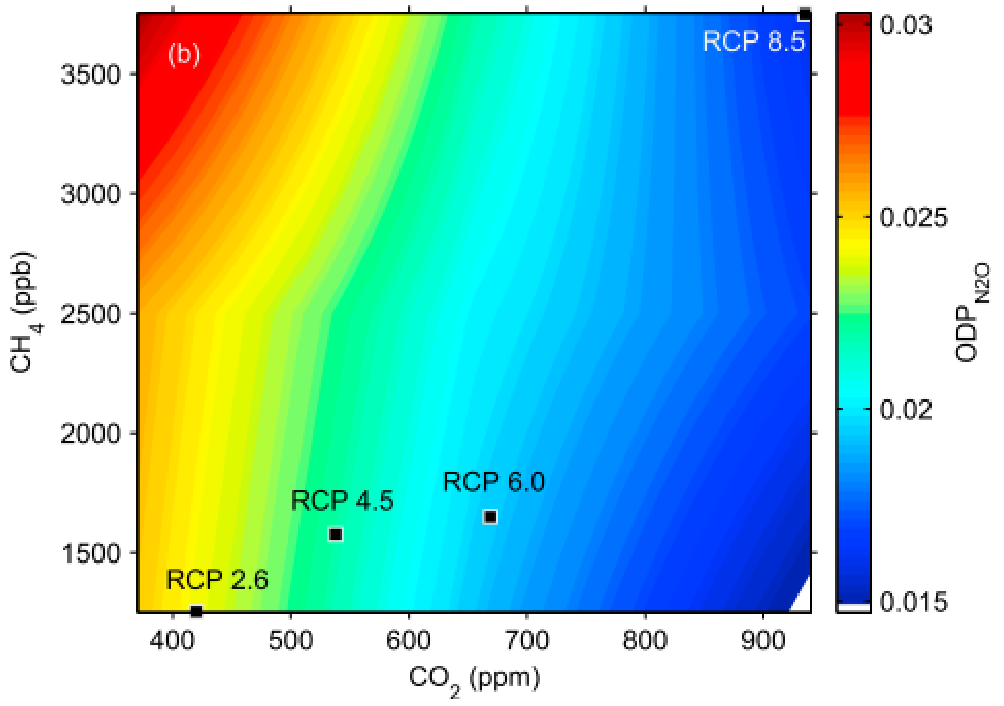
Change in global-mean column ozone due to substance i

$$ODP_i = \frac{\Delta\mu_{CFC-11} * \tau_i * m_{CFC-11} * \Delta[O_3]_i}{\Delta\mu_i * \tau_{CFC-11} * m_i * \Delta[O_3]_{CFC-11}}$$

- Dependent on atmospheric conditions (CO_2, CH_4, N_2O, Cl^-, temperature, etc.)
- 4-yearly update by World Meteorological Organization (WMO)
- Latest update: 2022

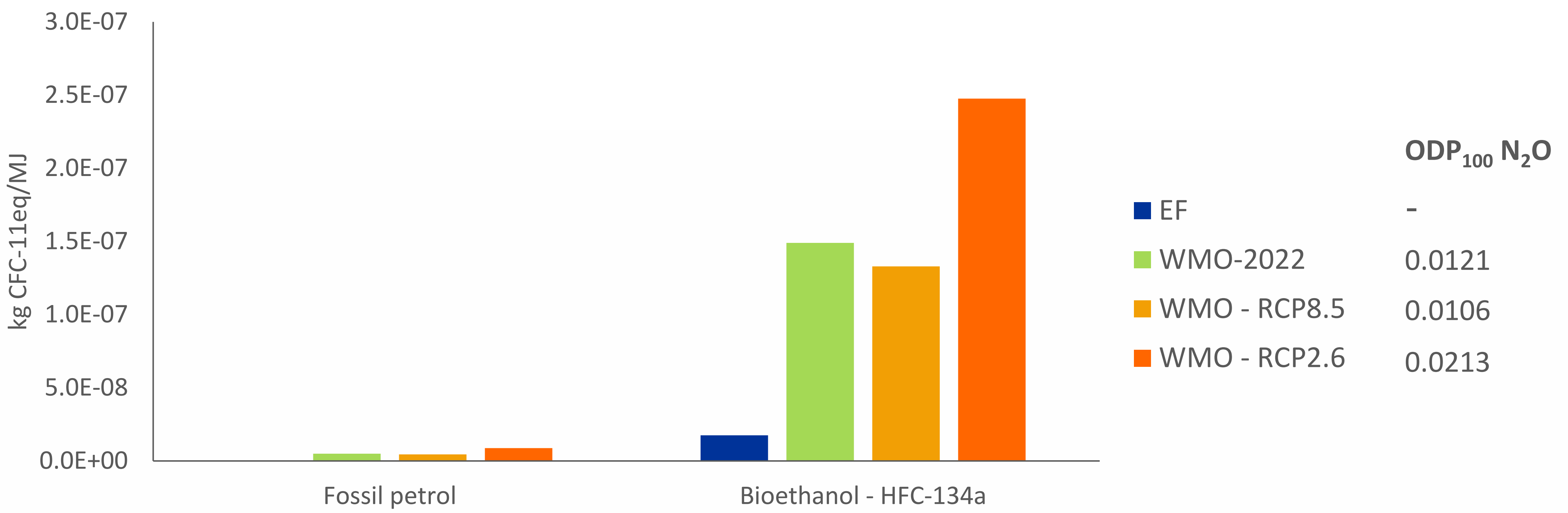
First attempt at prospective characterization factors for 2100

- CO_2 and CH_4 projections are available for the RCPs
- ODP of N_2O is twice as high in RCP 8.5 than in RCP 2.6
- Limitations of the model: future N_2O, Cl^-, and stratospheric aerosol concentrations not considered



Revell et al., 2015, The changing ozone depletion potential of N_2O in a future climate, Geophys Res Lett (42), https://doi.org/10.1002/2015GL065702

Conditions in 2022 are not a good estimate for future scenarios with high climate ambitions



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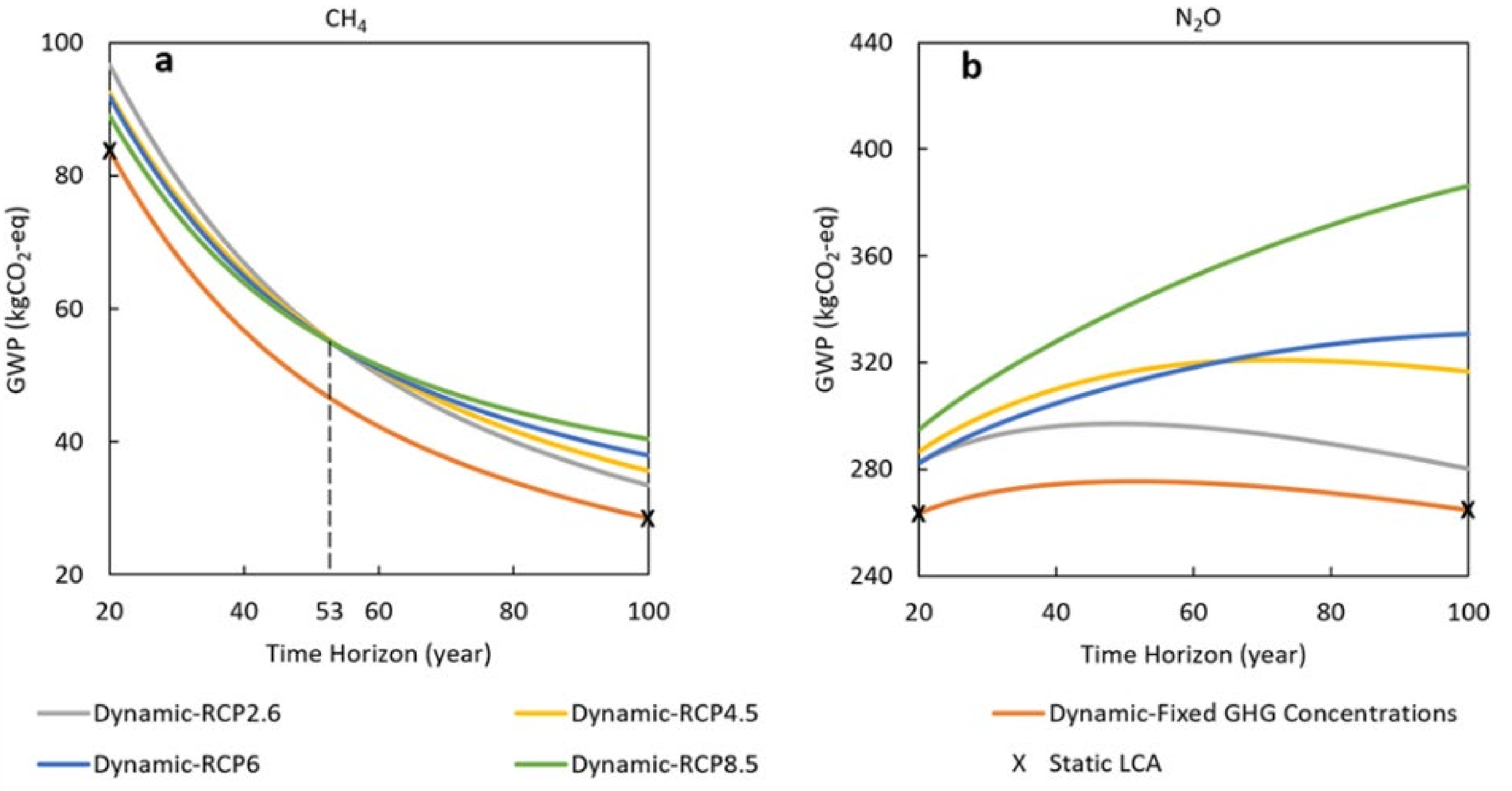
Prospective GWPs is particularly relevant when N_2O emissions dominate



Lan and Yao, 2022, Dynamic life cycle assessment of energy technologies under different greenhouse gas concentration pathways, Environ. Sci. Technol. 56, 1395-1404, https://doi.org/10.1021/acs.est.1c05923

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Work on prospective-dynamic characterization factors is ongoing

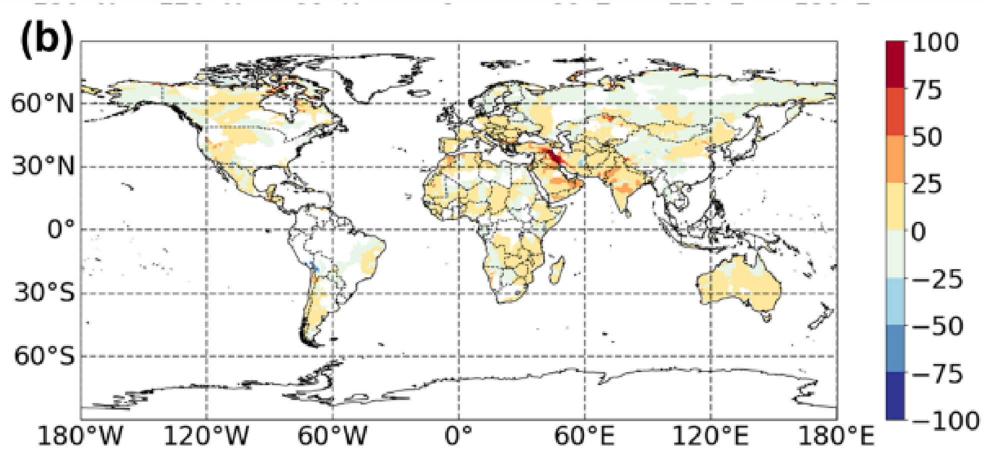
- **Dynamic_characterization** brightway package
  - Timo Diepers (RWTH Aachen)
  - Amelie Müller (CML-VITO)
  - Arthur Jakobs (PSI)
- Development of prospective-dynamic characterization factors for climate change ongoing
  - Cristina Madrid-Lopez (Autonomous University of Barcelona)
  - Susie Wu (CIRAIG)

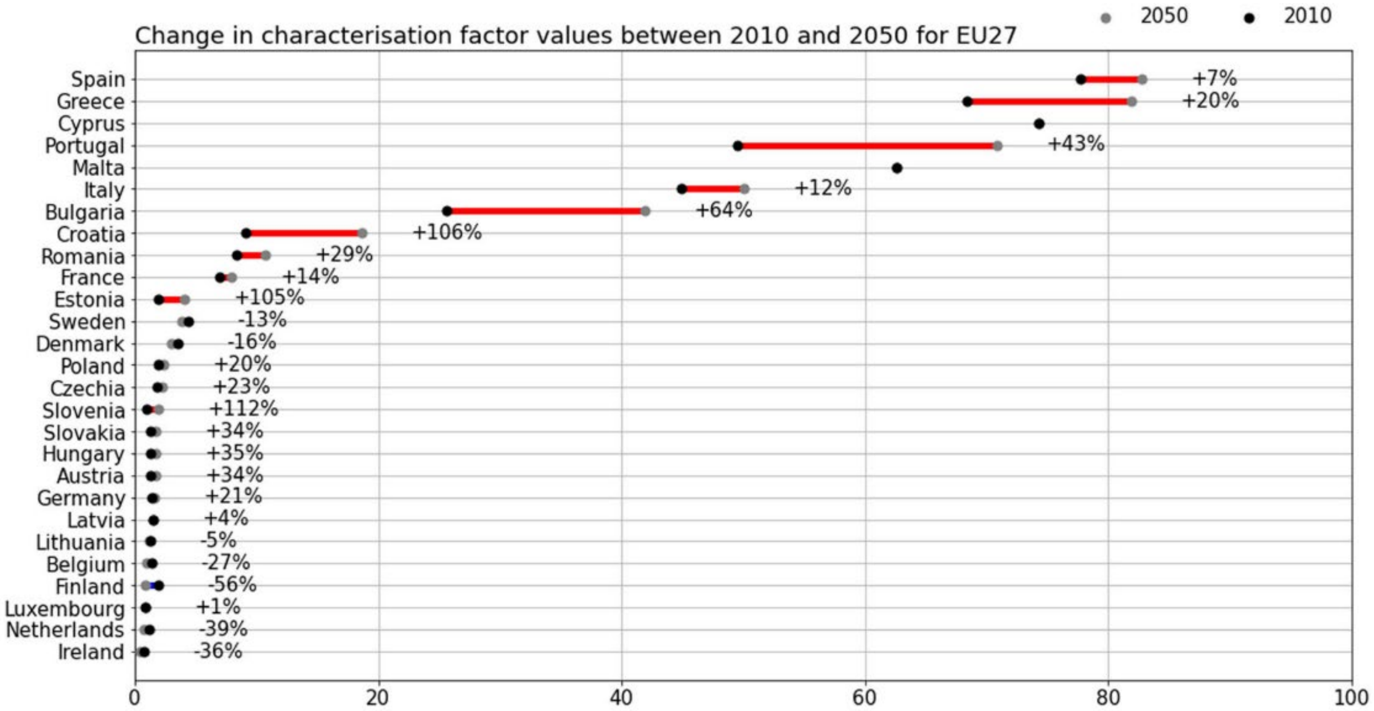
Want to contribute?
Add your (prospective)-dynamic characterization factors!

Prospective water scarcity characterization factors following SSP2-RCP6

From IMAGE

$$AMD_i = \frac{Availability_i - HWC_i - EWR_i}{Area}$$

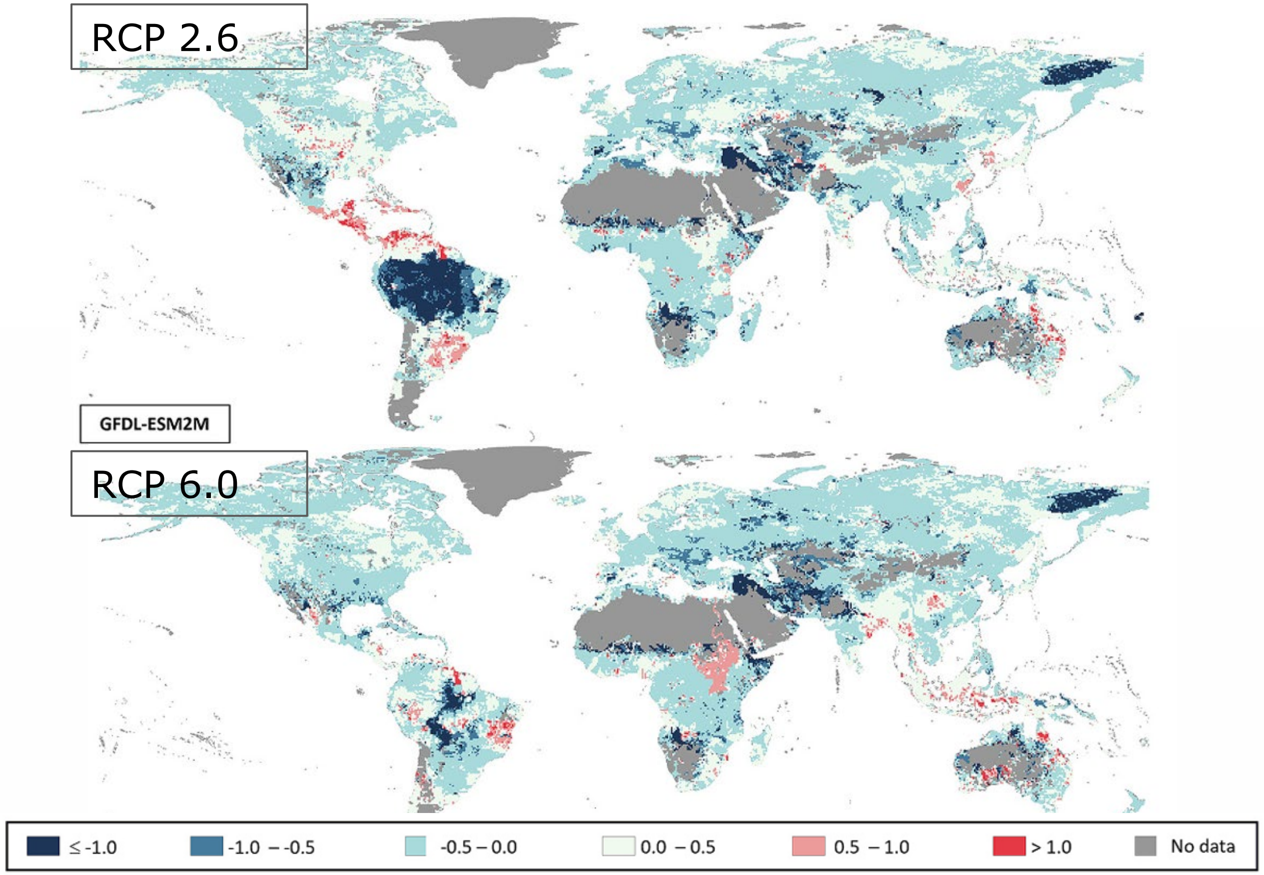




Baustert et al., 2022, Integration of future water scarcity and electricity supply into prospective LCA, J. Ind. Ecol. 26, 1182-1194, https://doi.org/10.1111/jiec.13272

Prospective characterization factors for freshwater eutrophication

- The fate of nutrients depends on climatic, hydrological and biochemical conditions
- Fate factors updated using Global Climate Models
- Effect factors updated using projections on global fish richness for different global temperature increases



Vasilakou et al., 2025, Global spatiotemporal characterization factors for freshwater eutrophication under climate change scenarios, Science of the Total Environment 959, 178275, https://doi.org/10.1016/j.scitotenv.2024.178275

Climate change is a driving force behind **changes** in **LCIA**

Directly affected :

- Acidification
- Ecotoxicity
- Eutrophication
- Human toxicity
- Ozone depletion
- Particulate matter formation
- Photochemical ozone formation
- Plastics
- Water depletion
- Land use (soil quality)

Not directly affected :

- Energy resource depletion
- Ionizing radiation
- Mineral resource depletion

More research into **other potential future effects** on all impact categories is needed

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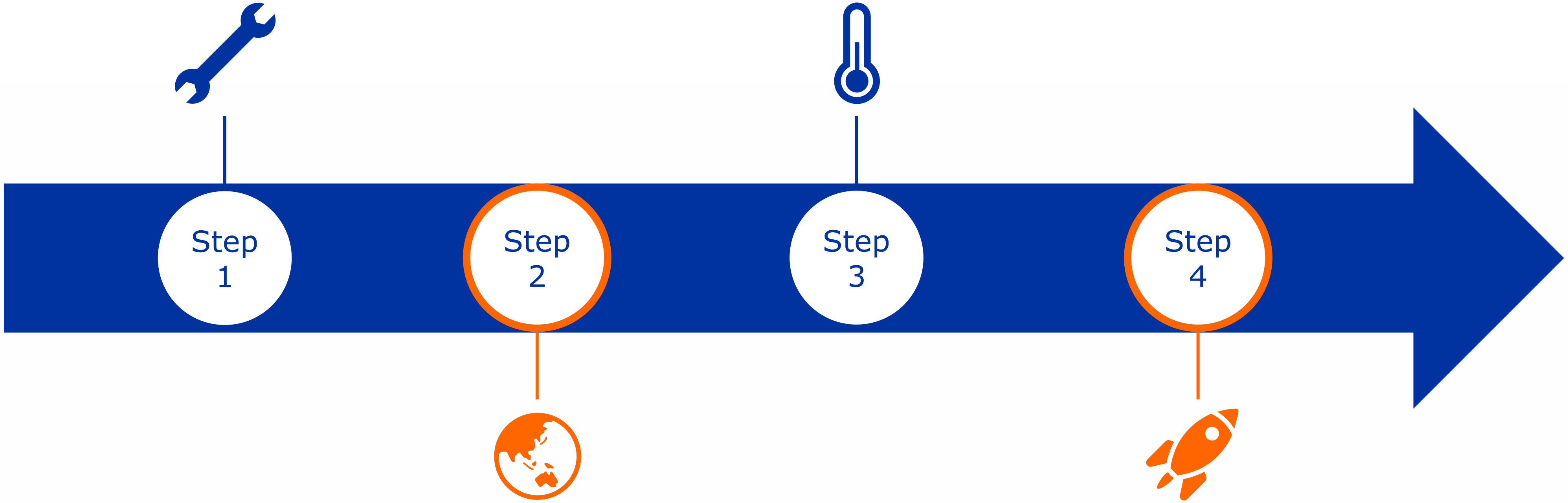
Key conclusions from the state-of-the-art

1. Good modelling for the future starts with good modelling today
   - Regular updates of impact assessment methods, following WMO, IPCC, etc.
   - Regionalization
2. RCPs are a good starting point for developing prospective characterization factors
   - Consistency with background scenarios
   - Harmonized scenarios among impact categories
3. Need for more detailed and specific models
   - For example, including stratospheric Cl^-, Br^-, and N_2O background concentrations
   - Effects of stratospheric aerosols
4. Collaboration with other fields
   - Atmospheric chemistry, IAM community, climate models, etc.

The next steps for advancing prospective LCIA

Improve existing models
e.g., with IPCC/ WMO
updates and regionalization

Model climate change effects
on other impact categories
following RCPs



Use regional characterization factors
as proxies for other climate conditions

Explore other effects
e.g., rocket launches

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