

• **EINE KREISLAUFFÄHIGE UND  
KLIMANEUTRALE FAHRZEUGFLOTTE  
IN ÖSTERREICH 2050**  
–  
**WIE DAS GEHEN KÖNNTE!**

Gerfried Jungmeier & Michael Schwingshackl  
EnInov 2024 18. Symposium Energieinnovation  
14.-16.02.2024, Graz/Austria



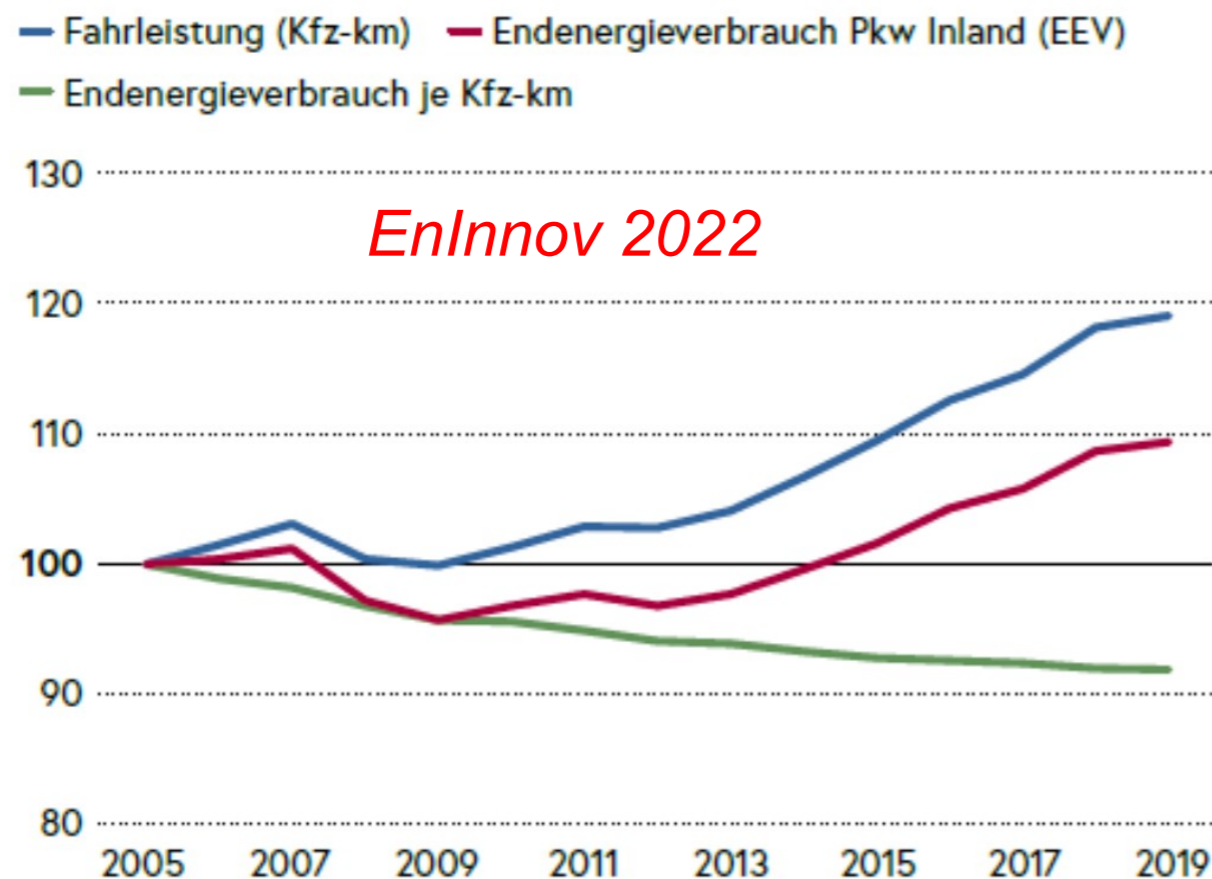
IEA HEV Task 46:  
*LCA of Electric Trucks, Buses,  
2-Wheelers and Other Vehicles*

Austrian participation  
financed by

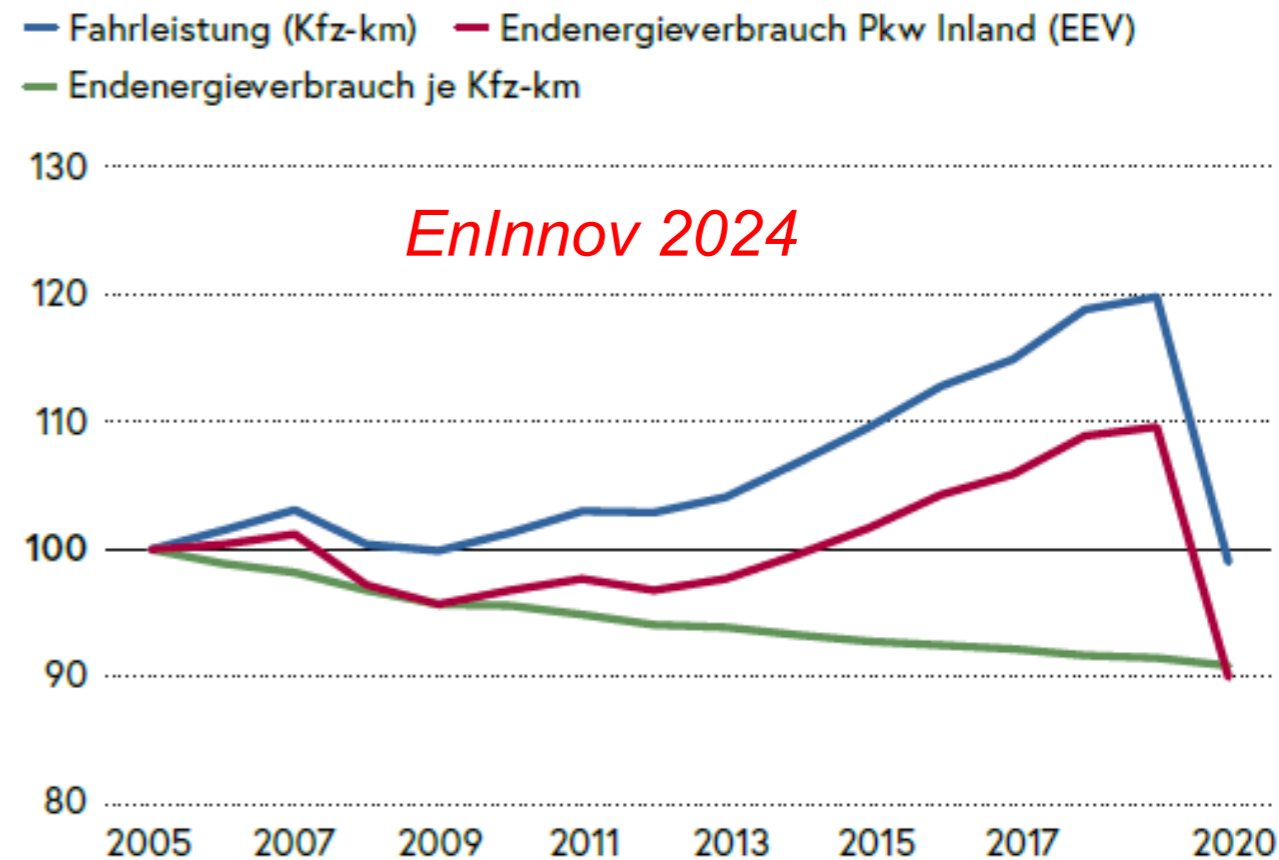


# Technologie-Entwicklung und Energiebedarf

$$\frac{\text{Energie}}{\text{Jahr}} = \frac{\text{Energie}}{\text{PKW - km}} * \frac{\text{PKW - km}}{\text{Jahr}}$$



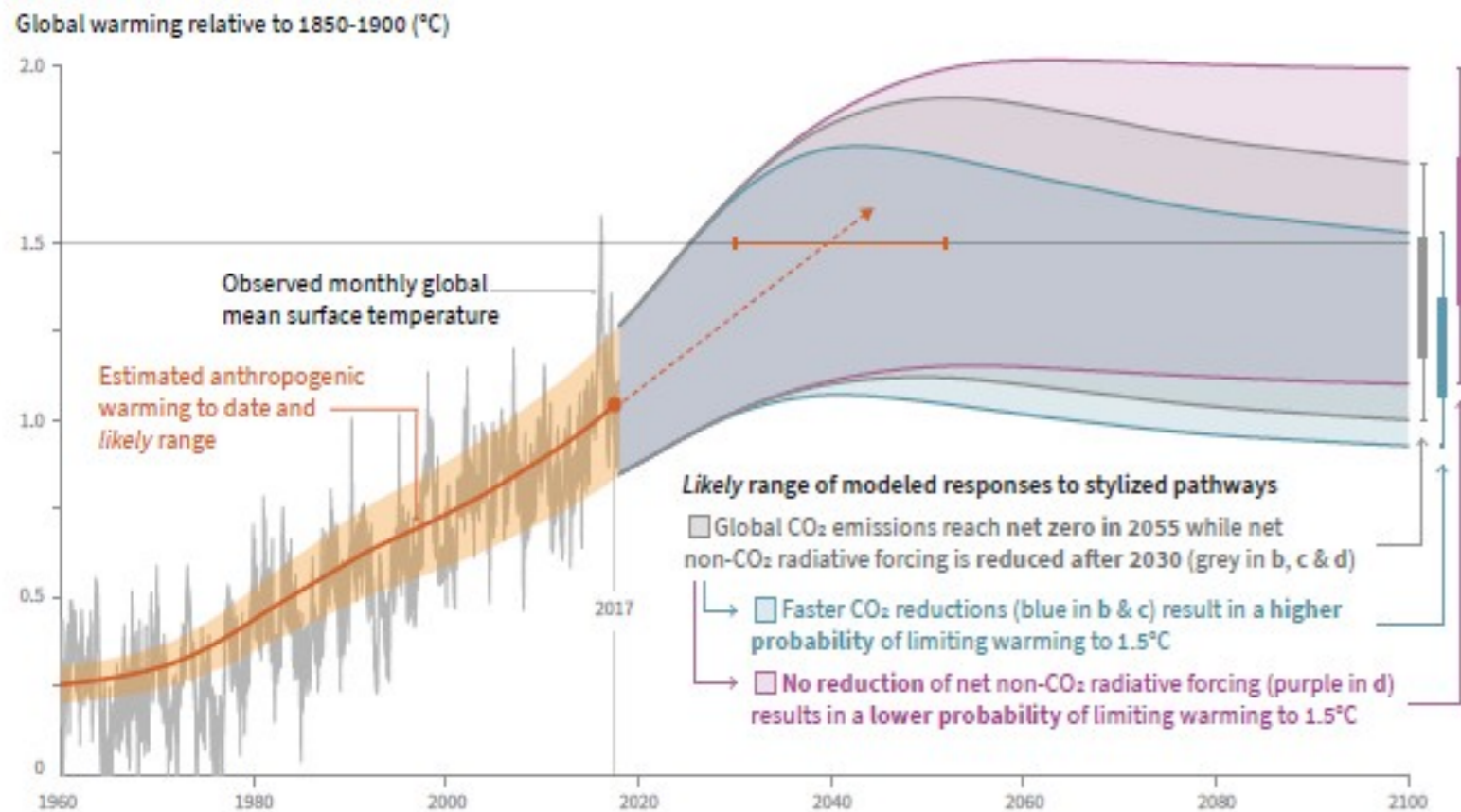
Quelle: Statistik Austria, Berechnungen Österreichische Energieagentur



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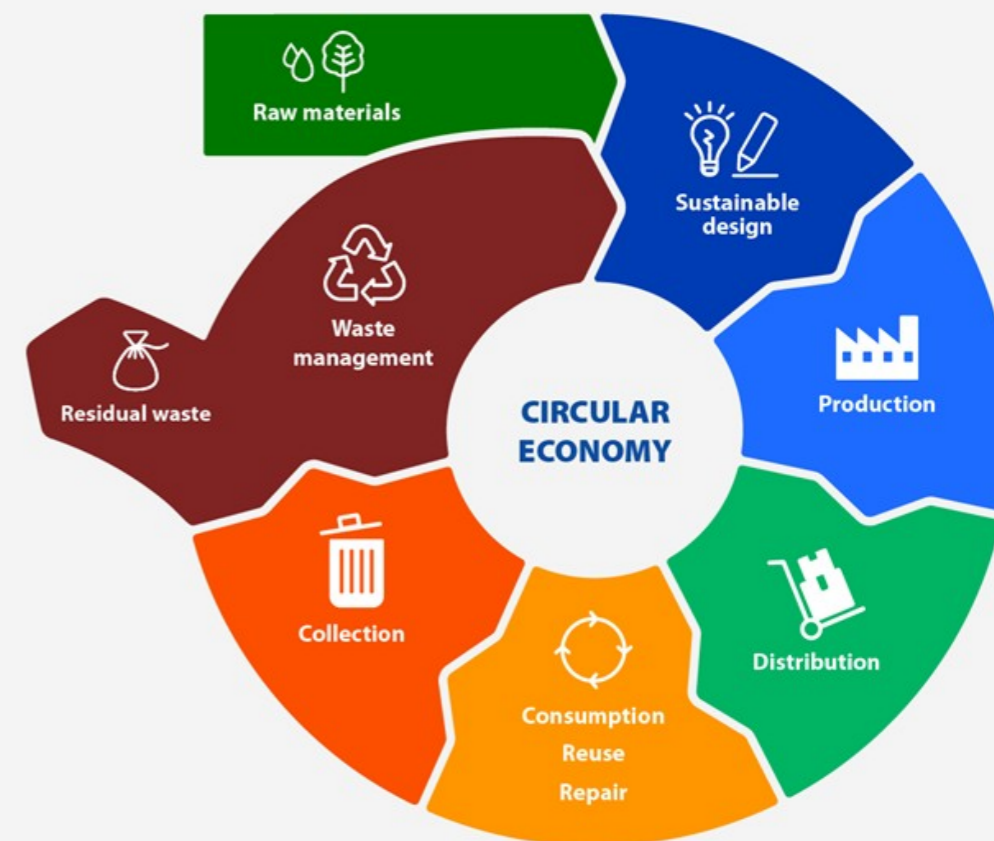
# The Challenges

## Global Warming



Quellen: [www.ipcc.ch](http://www.ipcc.ch), [www.europarl.europa.eu/news/en](http://www.europarl.europa.eu/news/en)

## Circularity

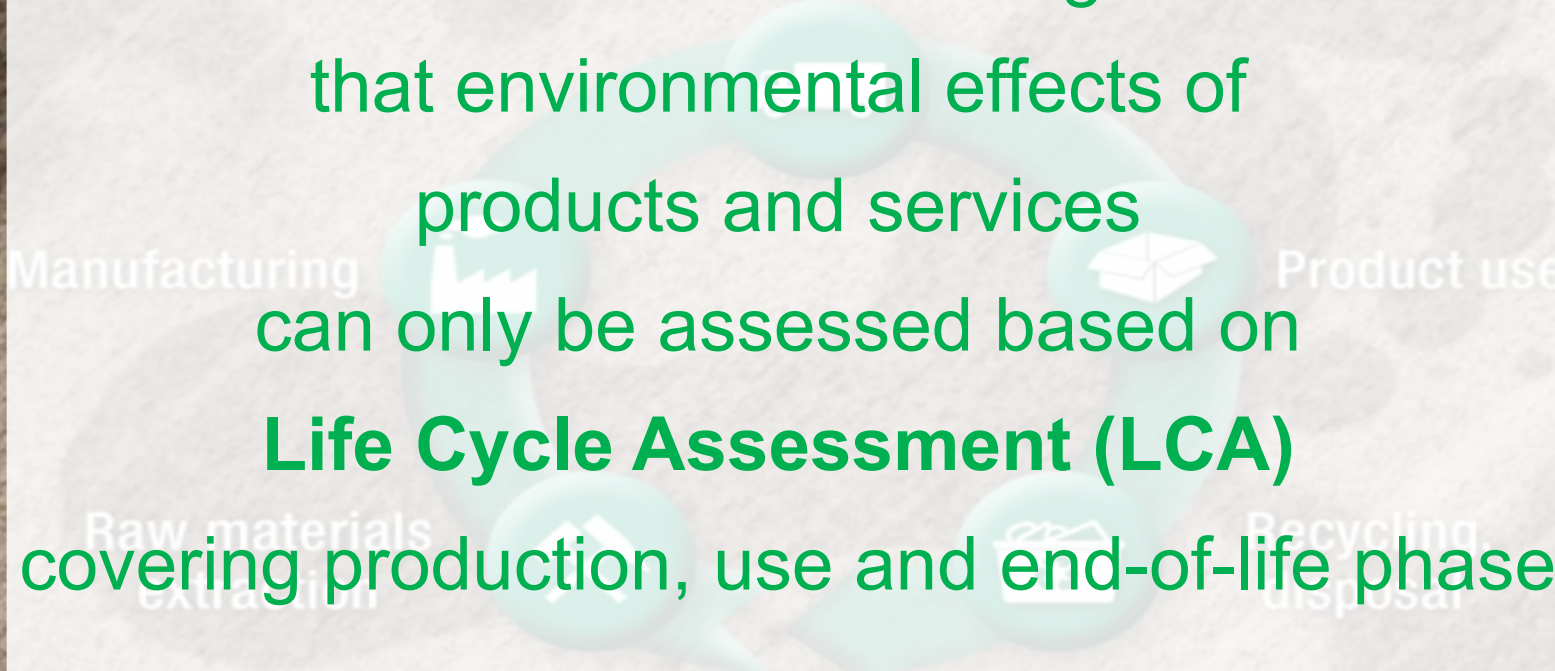


Source: European Parliament Research Service



# *Method for Environmental Assessment*

There is an international agreement that environmental effects of products and services can only be assessed based on **Life Cycle Assessment (LCA)** covering production, use and end-of-life phase



## **Additional §:**

**„Climate Neutrality“  
and  
„Circularity“**

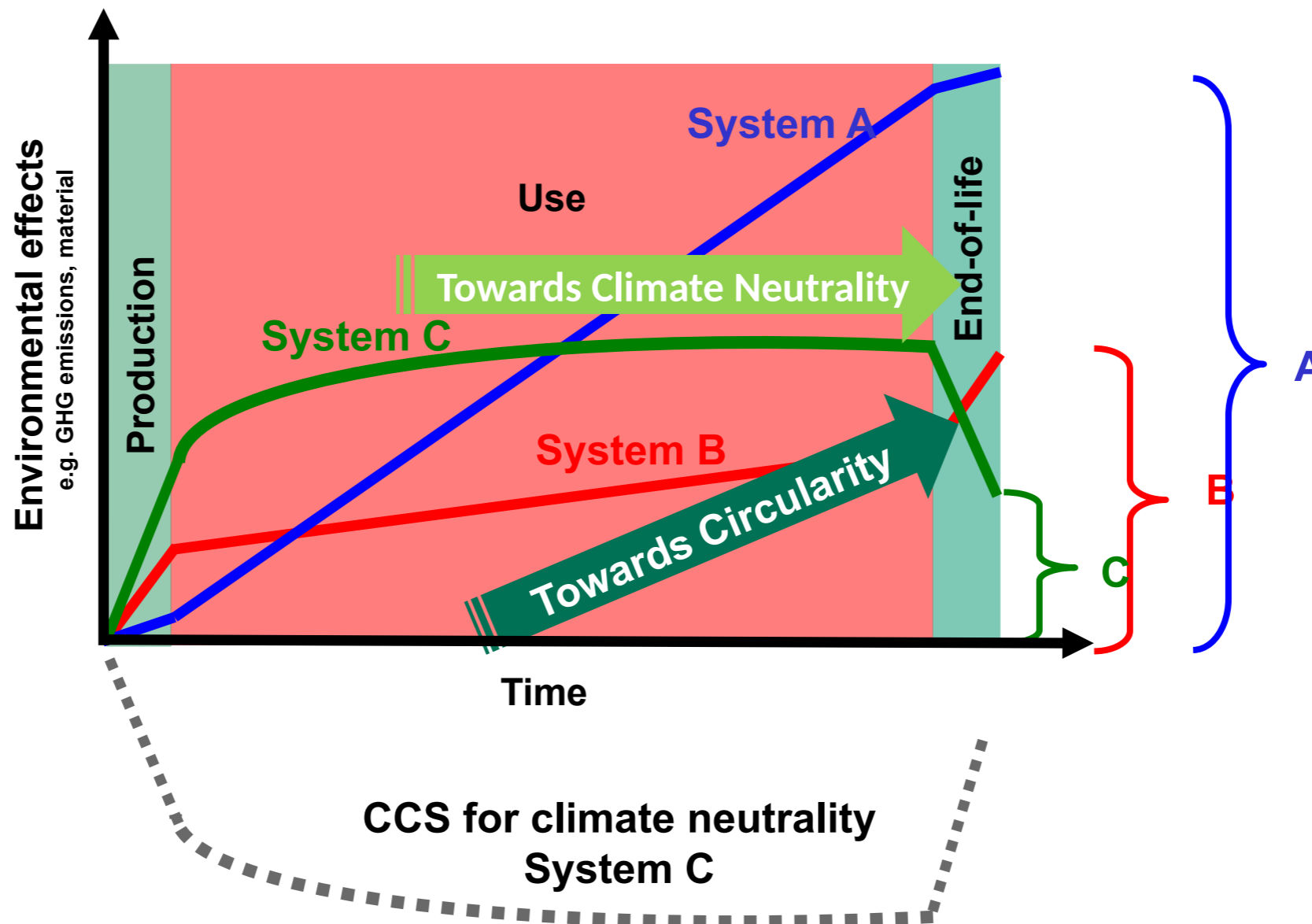
are only addressed by

**Dynamic Life Cycle Assessment**

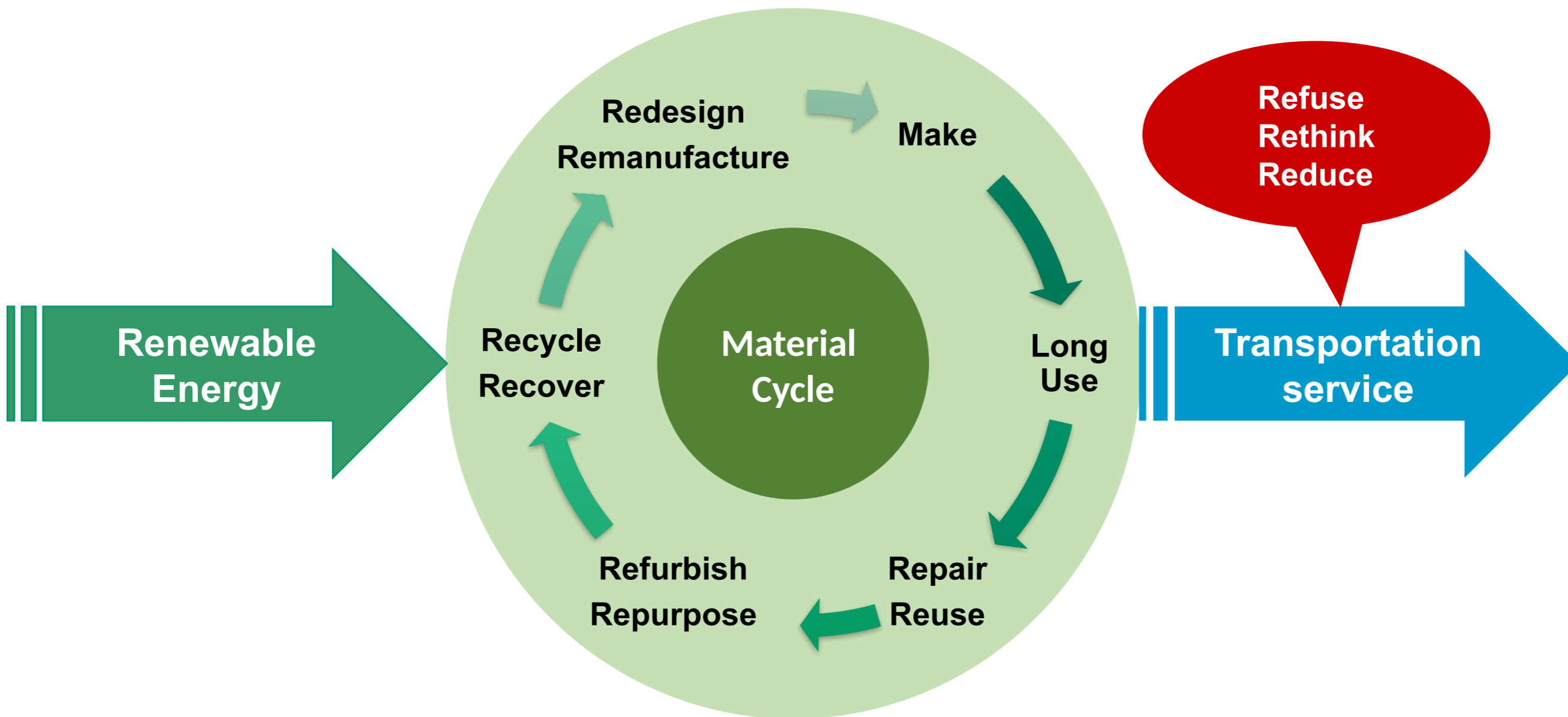
considering the timing of  
GHG emissions,  
raw material extraction, reuse&recycling.

# The Three Phases in Life Cycle

Dynamic LCA considers time of environmental effects



# *Circularity and Transportation Services*



# Initial Definitions

## „Climate Neutrality“ and „Circularity“

■ A **product or service** is „climate neutral“ and „circular“, if its whole life cycle - production, operation and end-of-life

■ **uses only**

- reused components (*reuse index*)
- secondary (recycled) material (*recycled content*,
- renewable energy

■ **makes**

- zero waste and
- zero GHG emissions

■ **Indicators for assessment**

■ **Circularity Potential**

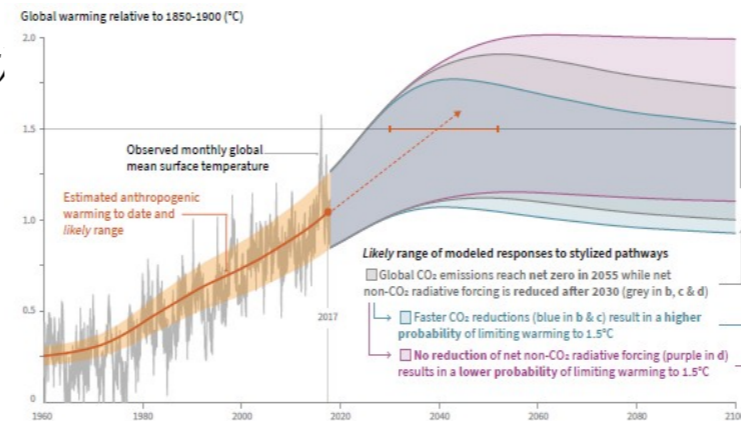
- Based on data of Inventory Analysis
- Material Circularity Index (MCI) based on mass flows over lifetime: 100% = circular (whereas: 0% = linear)
  - Linear Flow Index of materials ( $LFI_{material}$ )
  - Utility Factor of product ( $UF_{product}$ ): Utility = lifetime \* intensity of use
  - $MCI = LFI_{materials} * UF_{product}$

■ **Climate Neutrality Potential**

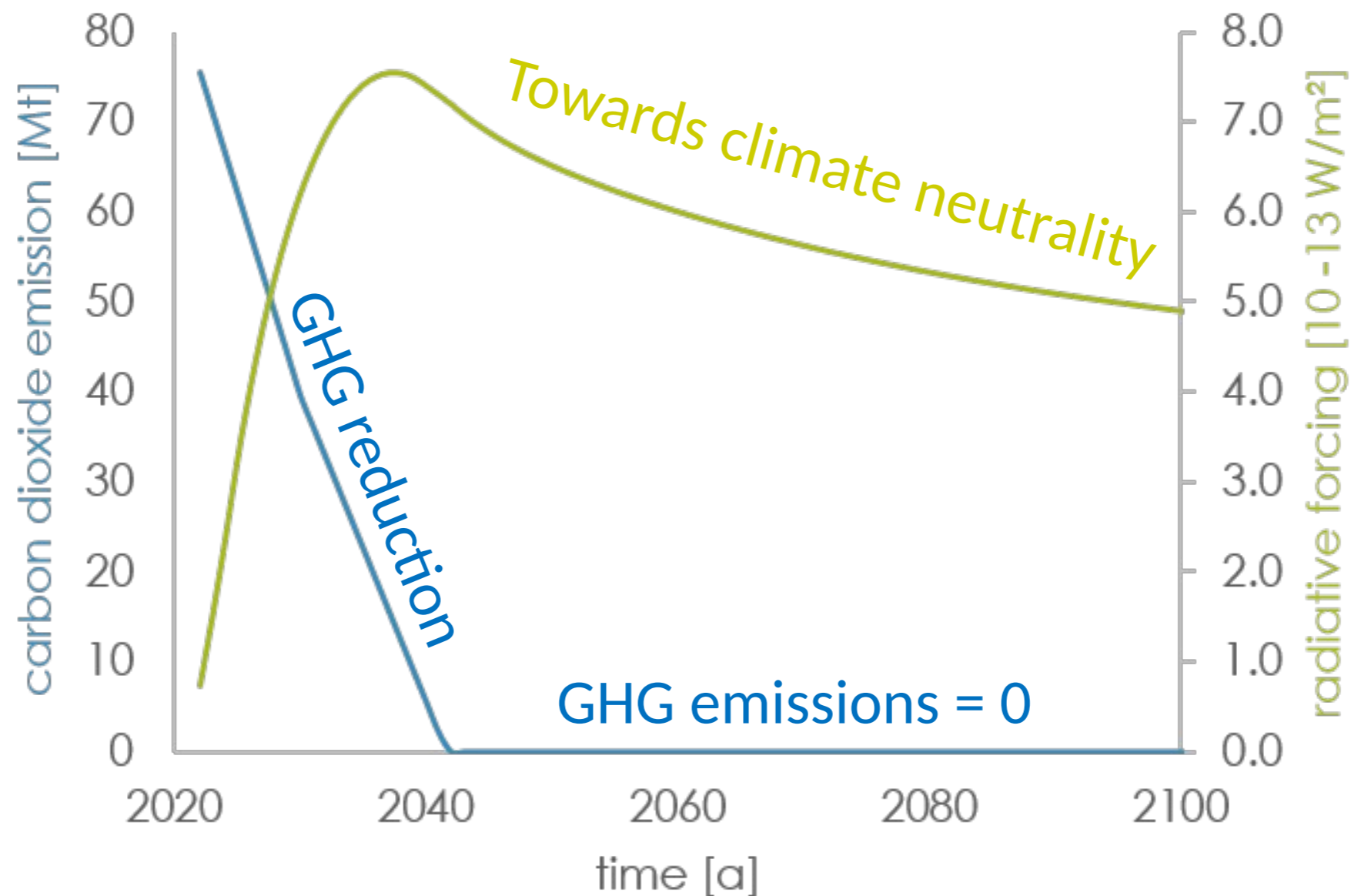
- Based on GHG emissions from Impact assessment
- Total radiative forcing at top-of atmosphere based on GHG emissions over lifetime in year 2100:  $W_{2100}/m^2 = 0$
- „Towards“ climate neutrality“:
  - Zero GHG emissions in operation phase: e.g. 0 kg CO<sub>2</sub>-eq/a
  - Change in radiative forcing: delta W/m<sup>2</sup>

■ **Concluding**

- *Climate Neutrality* and *Circularity* are visionary and long term targets
- **BUT:** future products and services must be developed and assessed **„towards“** *Climate Neutrality* and *Circularity*

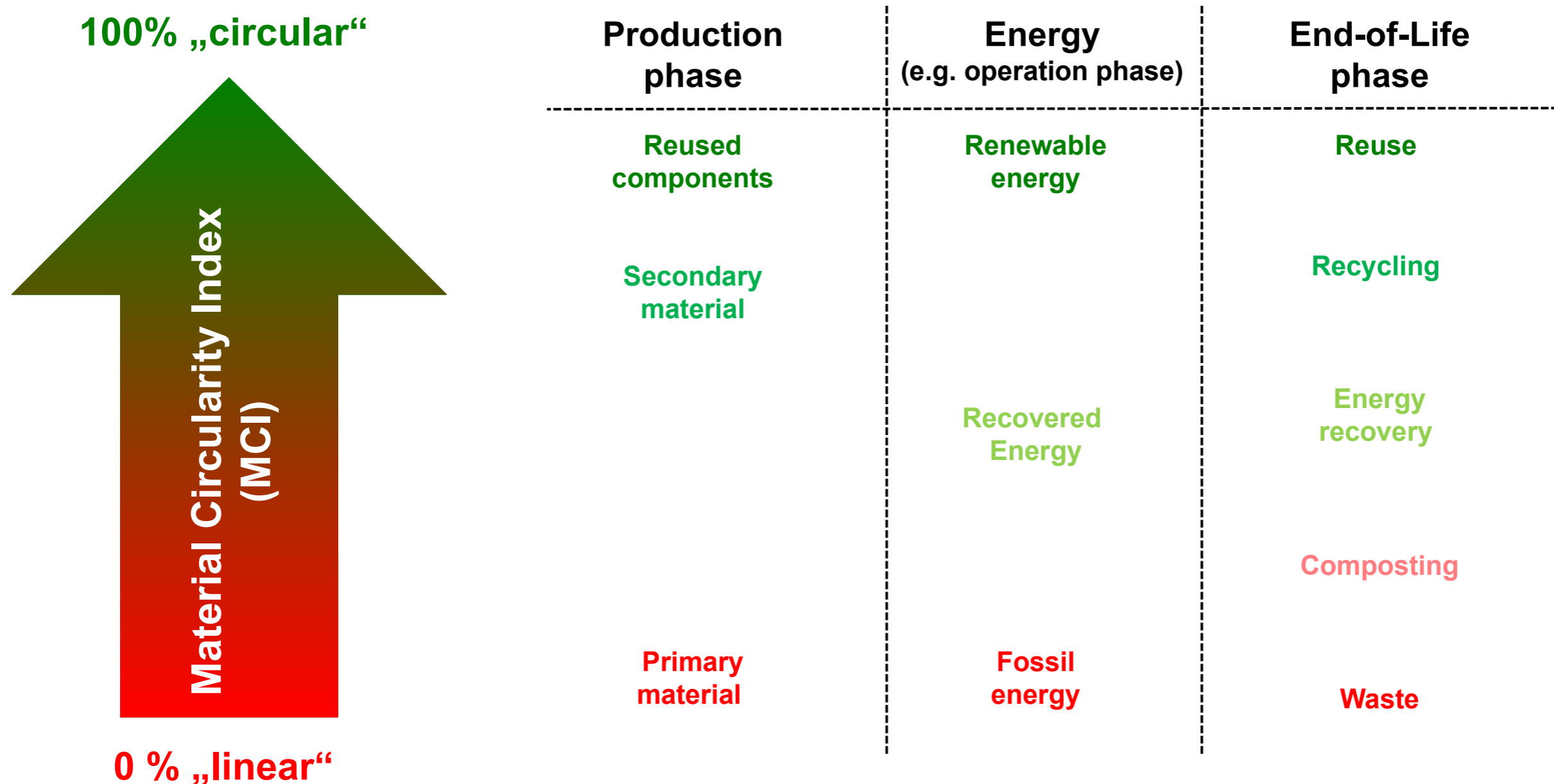


# Towards „Climate Neutrality“ from „GHG Reduction“ to „Zero GHG Emissions“





# Towards Circularity using the „Material Circularity Index (MCI)“



# Calculation of Material Circularity Index

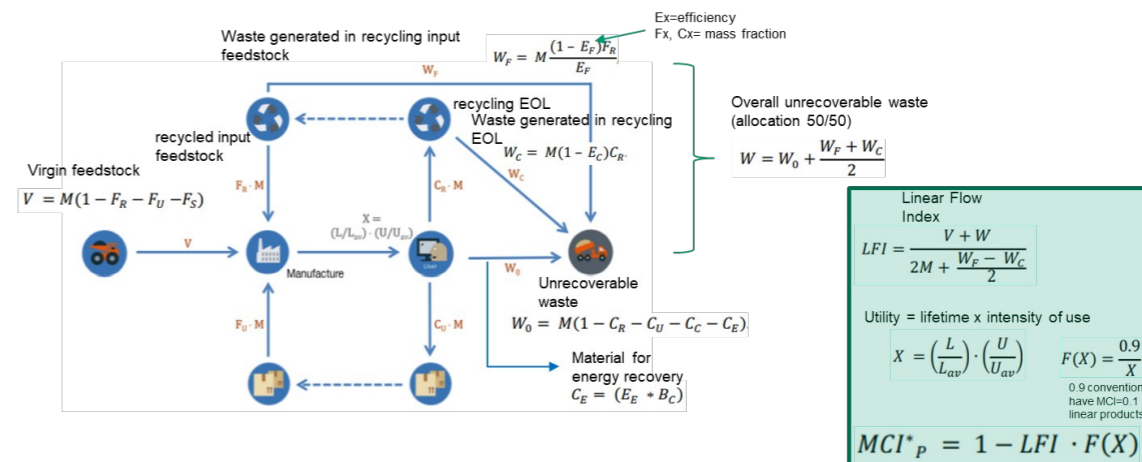
- **Linear Flow Index (LFI<sub>material</sub>)**: material specific

- **Utility Factor**

- Intensity of use: e.g. different payloads
- Lifetime: different lifetime truck (12 a) & energy supply (20 – 40 a)

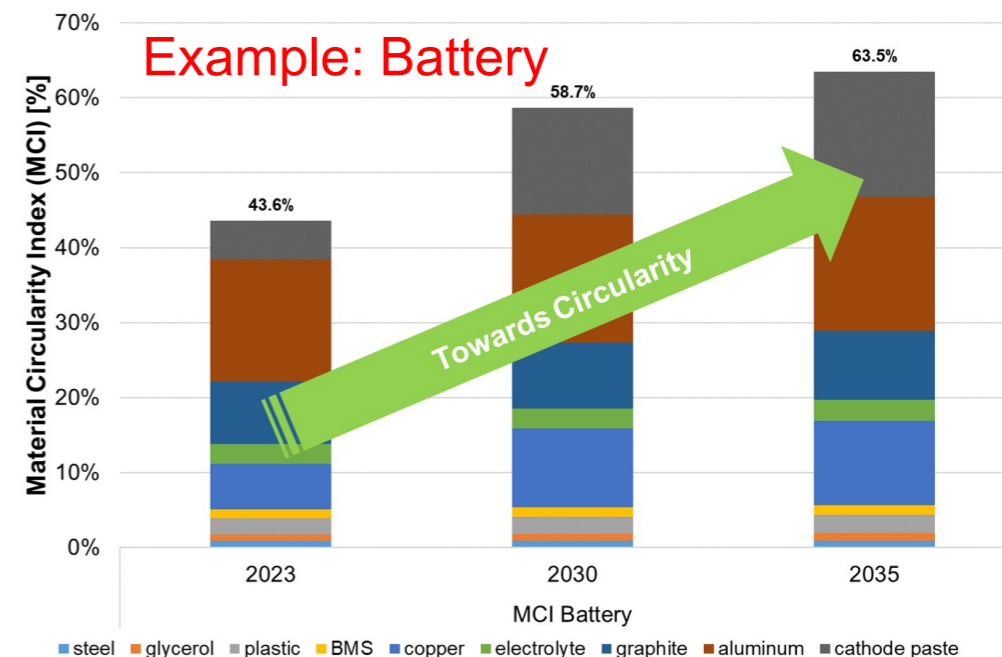
- **Material Circularity Index (MFI<sub>product</sub>)**:

- application product specific (e.g. battery, truck, power plant)
- $MCI = LFI_{materials} * UF_{product}$



Linear Product: MCI=0.1    Zero Waste Circular Product = 1  
 Additional: MCI for fossil energy: MCI = 0

Source: Calculation of „Circularity Indicators“ of Ellen MacArthur Foundation





# LCA Case Study Trucks: Goal & Scope and „Specialities“

**Aim:** Identify significant differences of environmental effects of trucks with different propulsion system/fuel for current (2023) state of technology

**Methodology:** dynamic life cycle assessment using generic global production data for materials

**Systems:** Specification of technology and systems with:

- Trucks: N1 (< 3.5 t), N2 (3.5 t > 12 t) and N3 (< 16 t) e.g. delivery truck and heavy long-haul trucks, any other
- Charging strategies, user profiles covered by typical driving cycles (weighting of urban rural and highway driving)

**Fuels:**

- Diesel
- e-diesel from renewable electricity mix and CO<sub>2</sub>
  - from air
  - concrete/steel production (if foreground data available)
  - Waste (if foreground data available)
- H<sub>2</sub> with FC from renewable electricity mix: GH<sub>2</sub>@700 bar and LH<sub>2</sub>
- Electricity for BEV and Catenary truck:
  - Renewable electricity mix: 50% wind, 25% hydro&25% PV
  - Sensitivity on country specific electricity mixes in 2022
- CNG and e-CNG (if foreground data available)
- e-MeOH with FC

**Functional units:**

- per truck-km
- per t-km



**Countries**

- AT, CA, CH, DE, ES, NO, SK, TK, UK, US (HEV)
- EU 27, JP, BR, CI (AMF)
- Africa, South America

**Impacts**

- GWP and perspectives towards climate neutrality
- Primary energy demand
- (Key) raw materials for trucks: LCI
- Circularity assessment with testing of ideas

**Based on**

- WtW of Heavy Duty Vehicle Evaluation from IEA TCP-HEV Task41 & AMF Annex 57
- LCI data from Argonne for vehicle production and EoL, e.g. material mix of components

**Documentation**

- Slide show
- Summary

**Timing:** finalisation end of 2023

**Electricity mix**

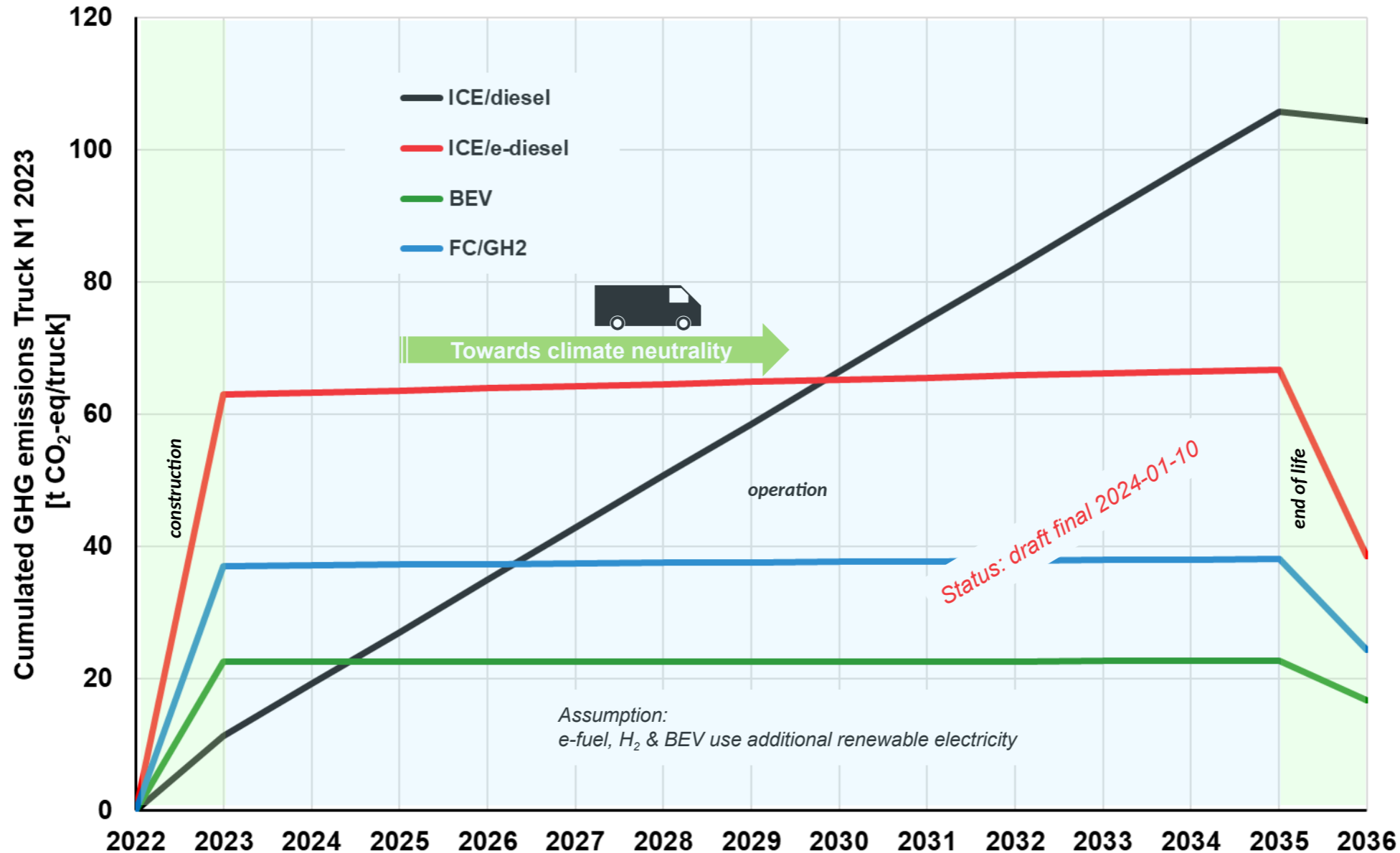
- Initial focus on **renewable electricity mix** (PV, wind, hydro)
- Installation of additional renewable electricity generation in „**production phase**“ of truck, reflecting different lifetimes
- Infrastructure for charging and catenary lines**
- Additional reflecting changing in national electricity mix between 2023 – 2035 during lifetime of truck in sensitivity analysis

**Specialities**

- Initial reflection of „**climate neutrality**“ (GWP=0!)
- Initial ideas and testing on „**circularity**“
- GWP of **direct H<sub>2</sub> emissions**
- Identify **significant differences** between electricity, hydrogen and e-fuels
- Discussion of definition/setting of **estimated ranges**
- Focus on significant differences
- Testing of **communication** of estimated ranges

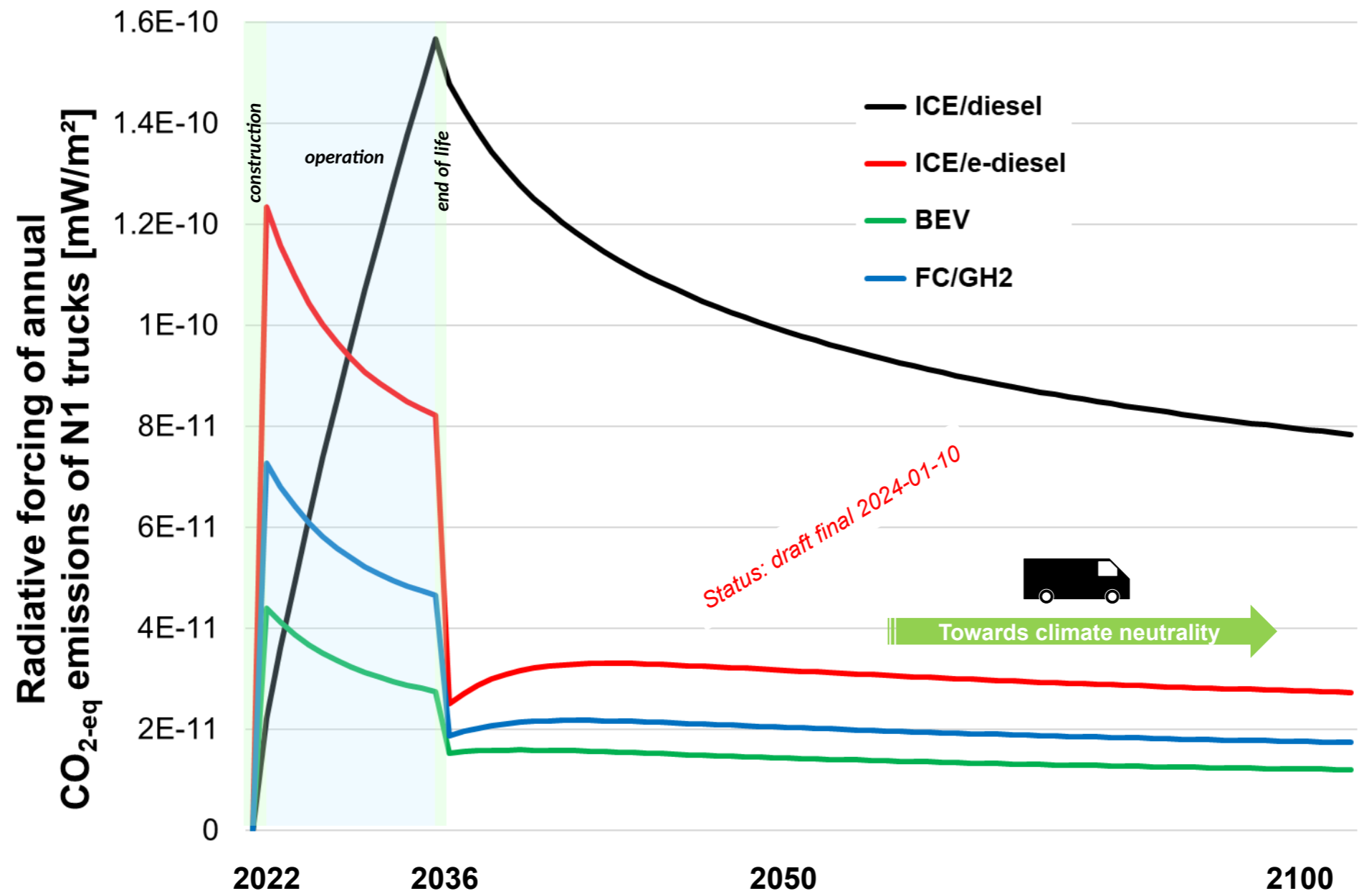
# Cumulated GHG-Emissions over Lifetime: N1 Trucks

12



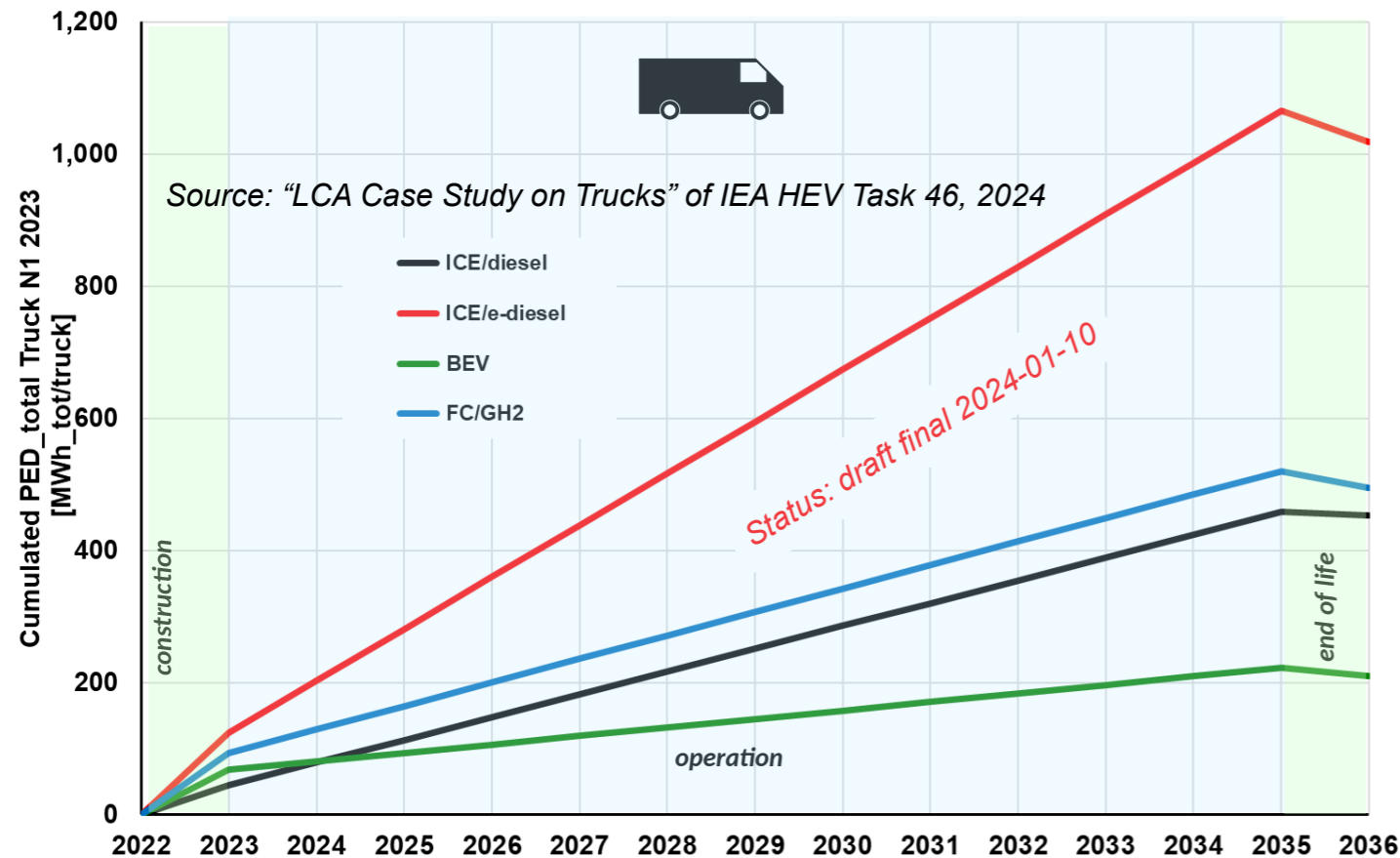
# Climate Neutrality Potential: Radiative Forcing over Lifetime: N1 Trucks

13

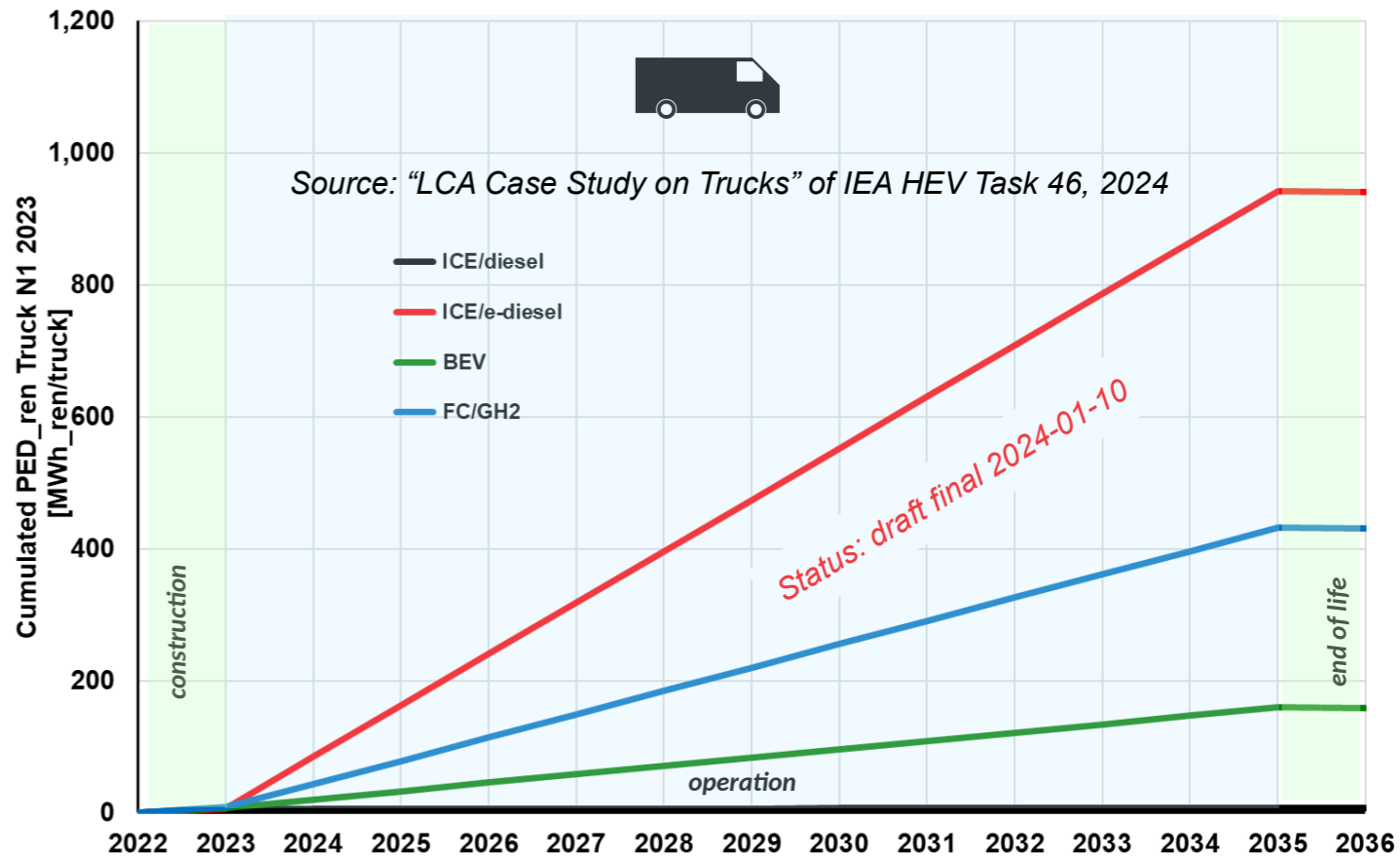


# Cumulated Primary Energy over Lifetime: N1 Trucks

## Total primary energy



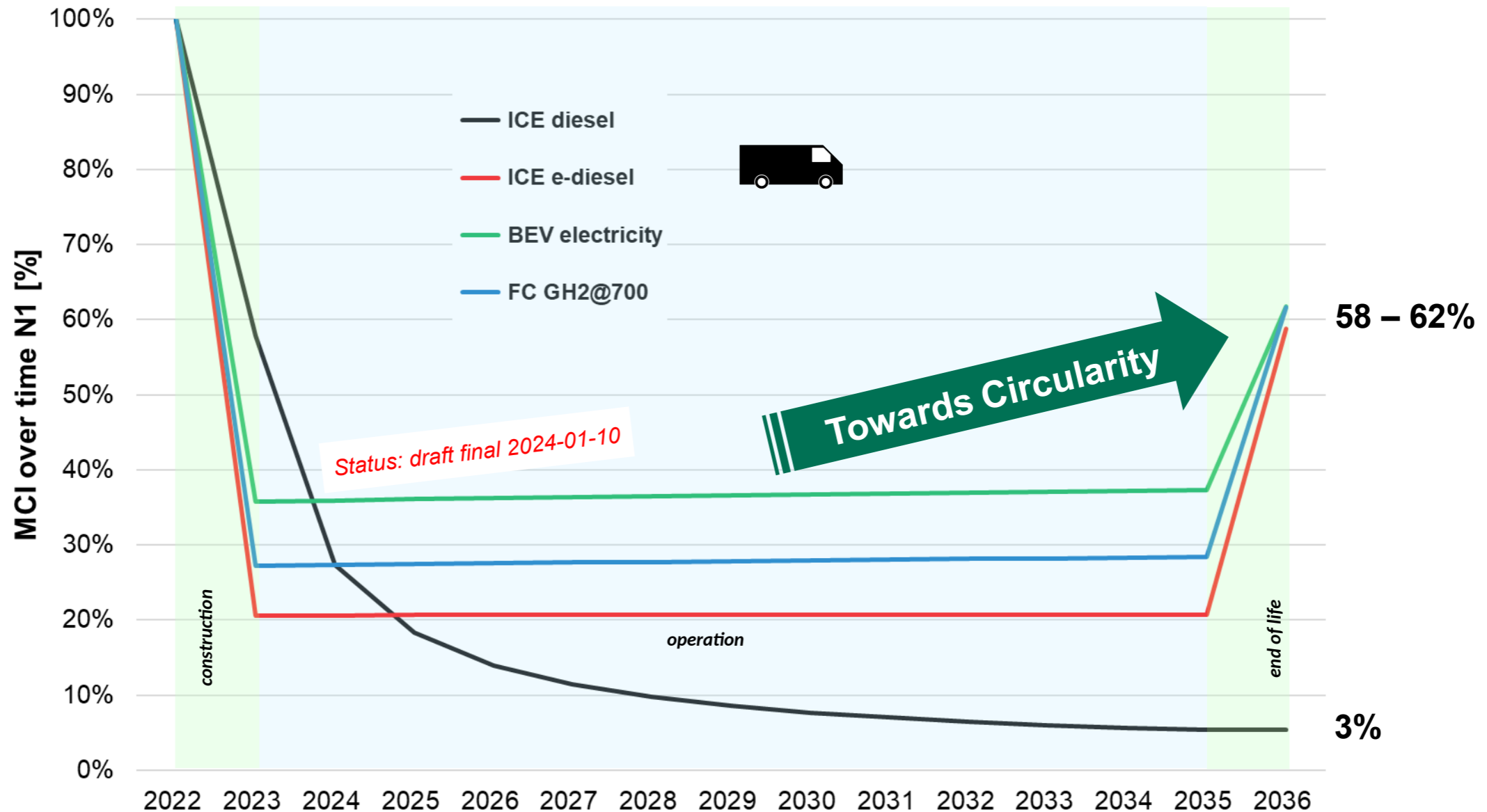
## Renewable primary energy



Assumption:  
e-fuel, H<sub>2</sub> & BEV use additional renewable electricity

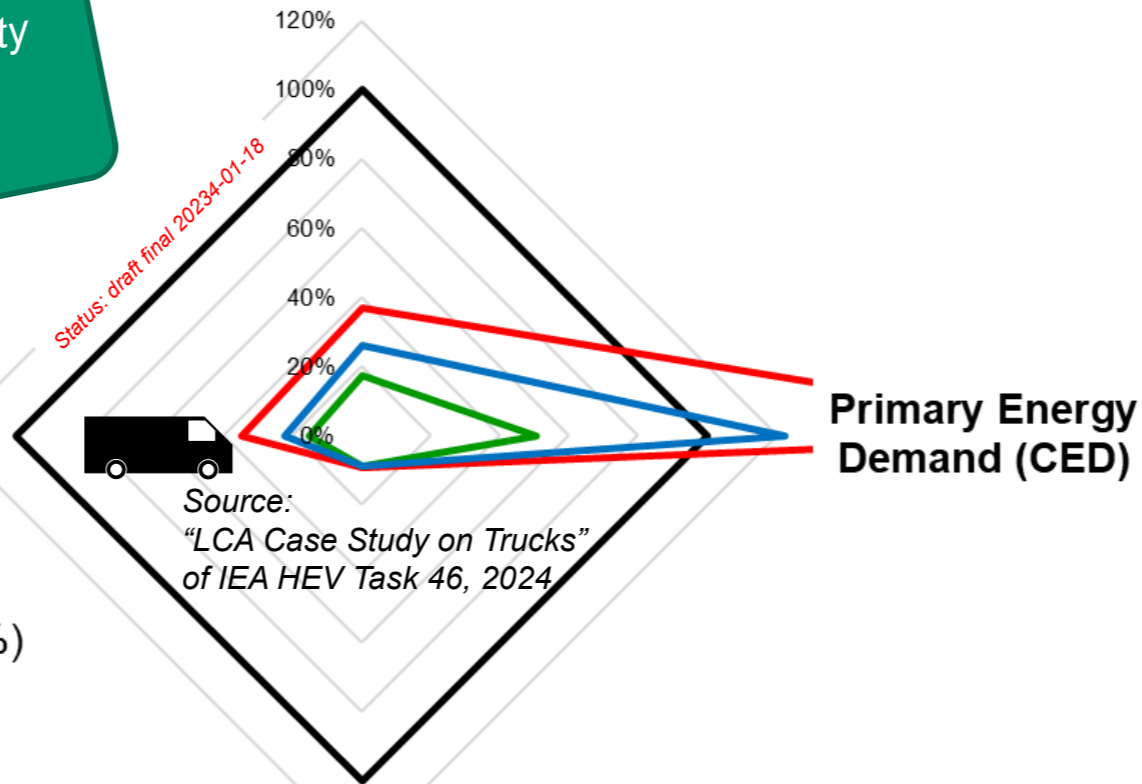
# Material Circularity Indicator (MCI) over Time: N1

15



# Overall Results: N1 Trucks

Global Warming Potential (GWP): GHG emissions



Status: draft final 2023-01-18

Source: "LCA Case Study on Trucks" of IEA HEV Task 46, 2024

**Initial answer:**  
 YES, "Climate Neutrality Potential" and "Circularity Potential" are two additional impacts categories not covered yet in LCA!

Climate Neutrality Potential (CNP): radiative forcing in 2100

Circularity Potential (CPO): 1/Material Circularity Index

- N1 ICE/diesel (100%)
- N1 ICE/e-diesel
- N1 BEV
- N1 FC/GH2



# Fahrzeugflotte in Österreich: Parameter für zwei Szenarien: „BEV“ und „WAM“



■ **WAM-Szenario:** nach UBA und BMK (Stand 2023)

## ■ **BEV-Szenario**

### ■ **THG Reduktionsziele**

- 2030: Österreich 48% Reduktion (vergl. 2005)
- 2040: Österreich „klimaneutraler“ Verkehrssektor
- 2050: EU und USA klimaneutral
- 2060: Rest der Welt klimaneutral

■ **Flotten-Modellierung** mit NEMO (Network Emission Model) der OLI (Österreichische Luftschadstoff-Inventur)

- **Unterschiedliche Anteile der Neuzulassungen** ab 2022: BEV und ICE/PHEV
- Nur **österreichische Fahrzeuge** (ohne „Tanktourismus“)
- **Jahreskilometer:** konstant ab 2022 (außer ÖV)
- **Fahrzeugflotte:** konstant ab 2022
- **alle Fahrzeugkategorien:** PKW, LNF, Solo-LKW, SZG, Linien- & Reisebusse, Motorräder, (U-)Bahn, Tram (Außer Schiffe, Flugzeuge, Off-road-Fahrzeuge)

■ **Erneuerbarer Strom** für BEV & WAM: Ausbau der erneuerbaren Stromerzeugung in Österreich bzw. Ausland integriert in bestehende erneuerbare Stromerzeugung

■ **Menge Biotreibstoffe:** bleibt etwa konstant ab 2020

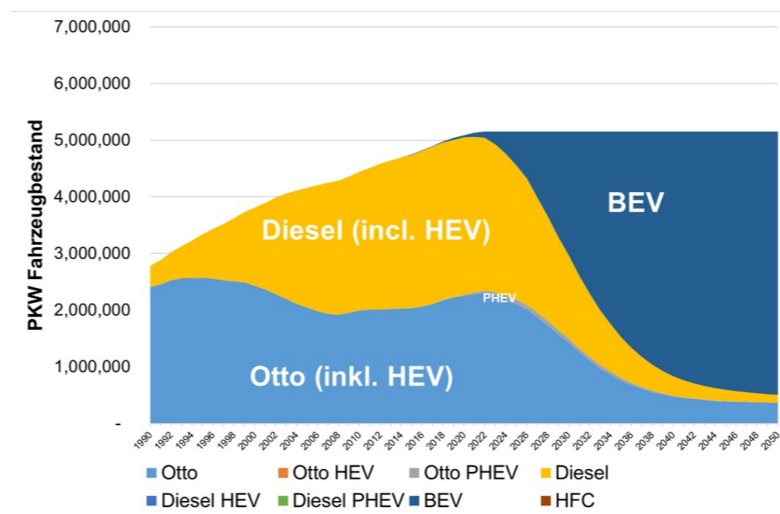
## ■ **Kooperation**

- JOANNEUM RESEARCH (LCA & Modellierung)
- Graz University of Technology (Fahrzeugflotten)
- IEA HEV Task 30&46 (Mitarbeit Methode)

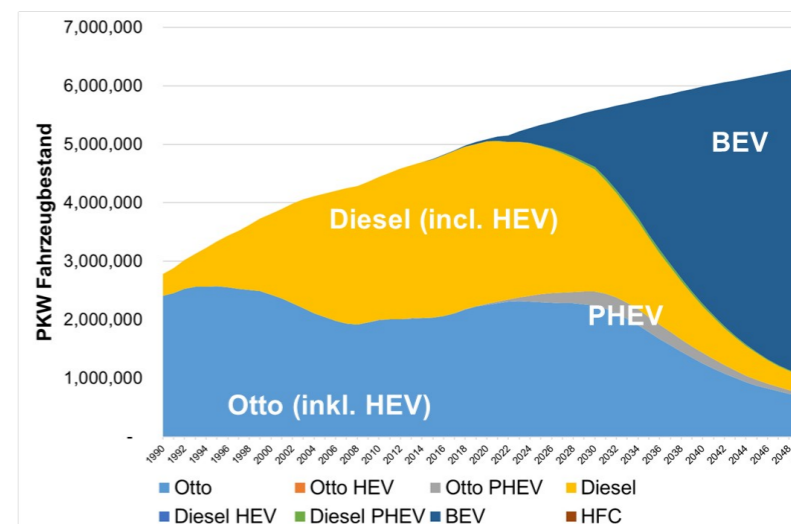
# Modellierung mit Flottenmodell und dynamischer LCA

Entwicklung Fahrzeugbestand

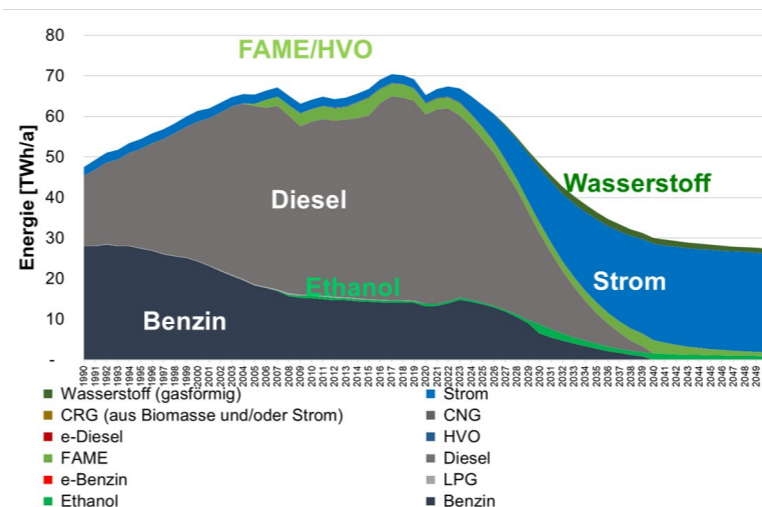
BEV-Szenario



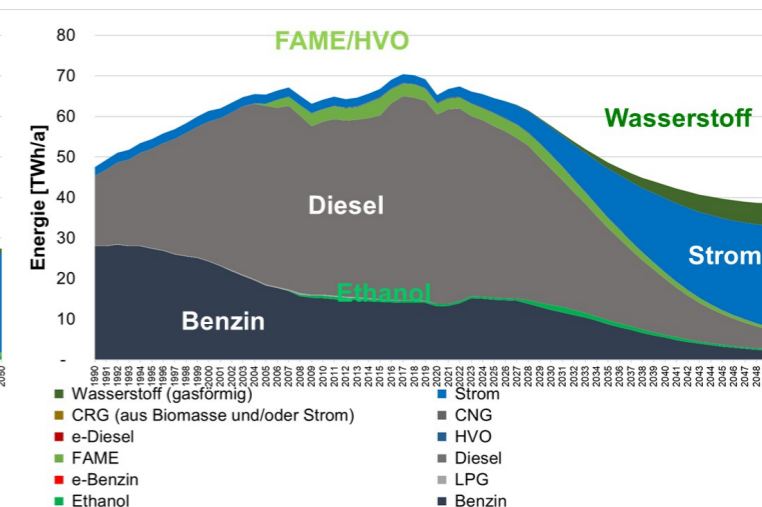
WAM-Szenario



BEV-Szenario



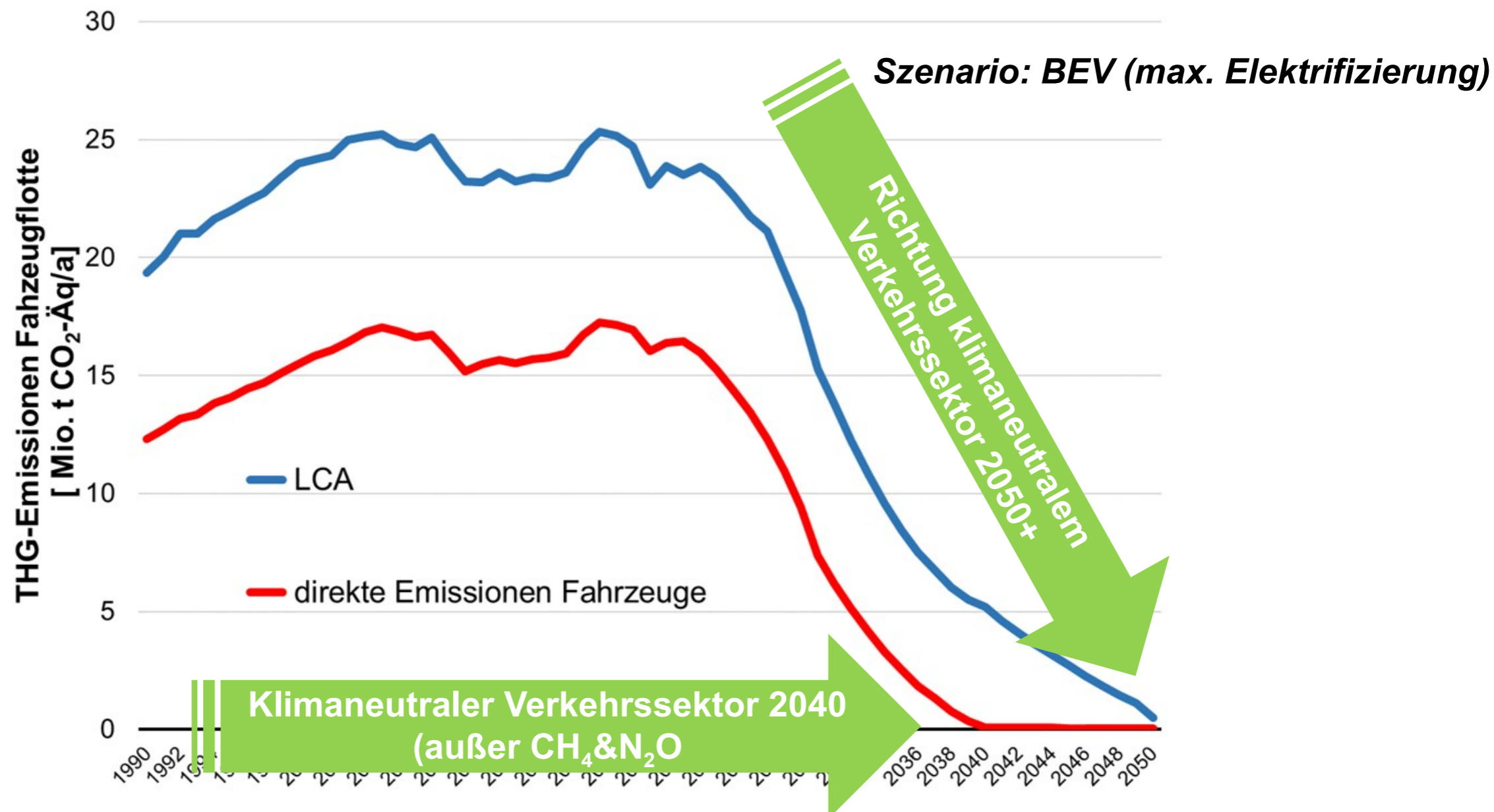
WAM-Szenario



Entwicklung Endenergiebedarf

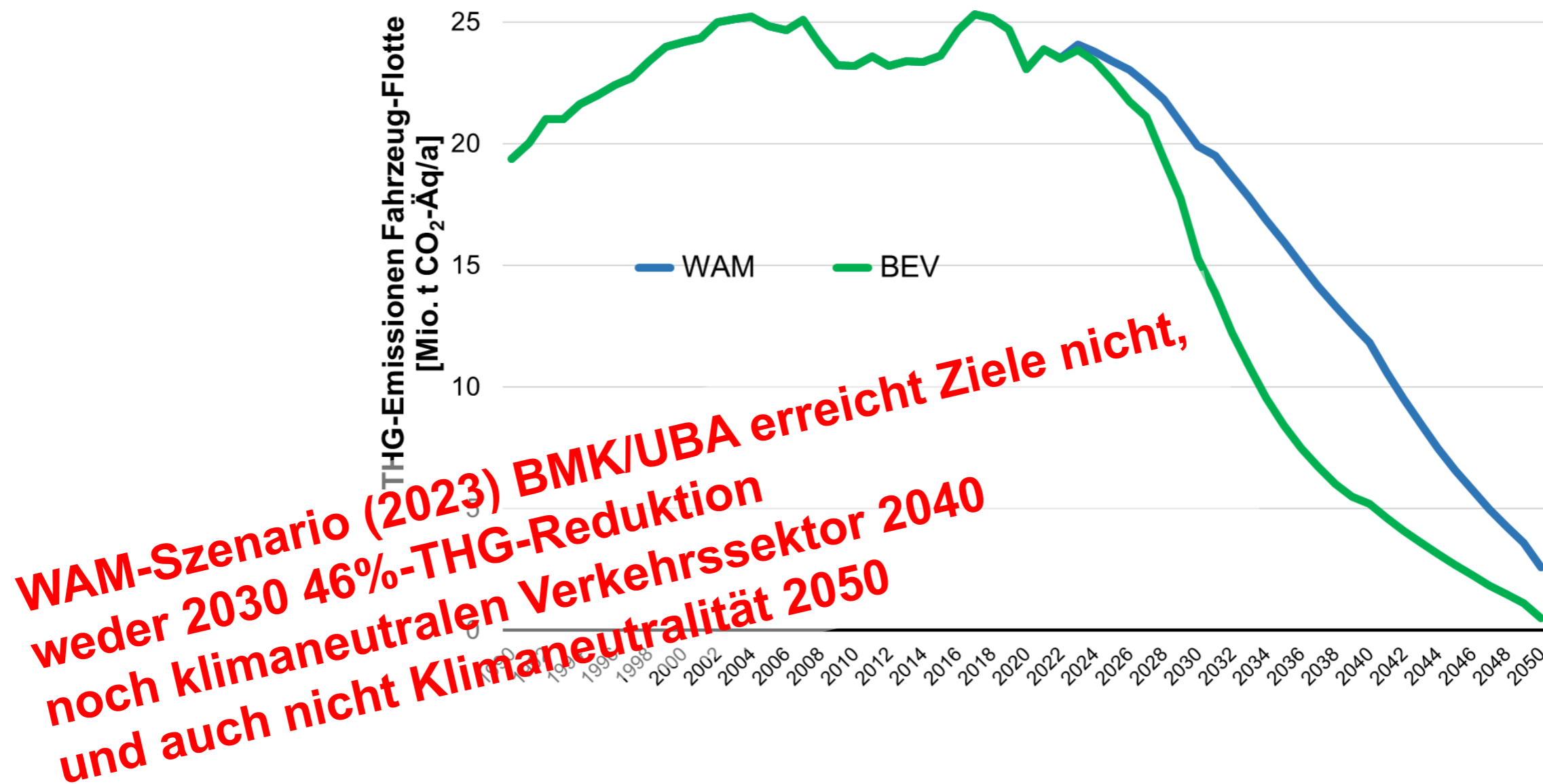
# THG-Emissionen der Fahrzeugflotte

19

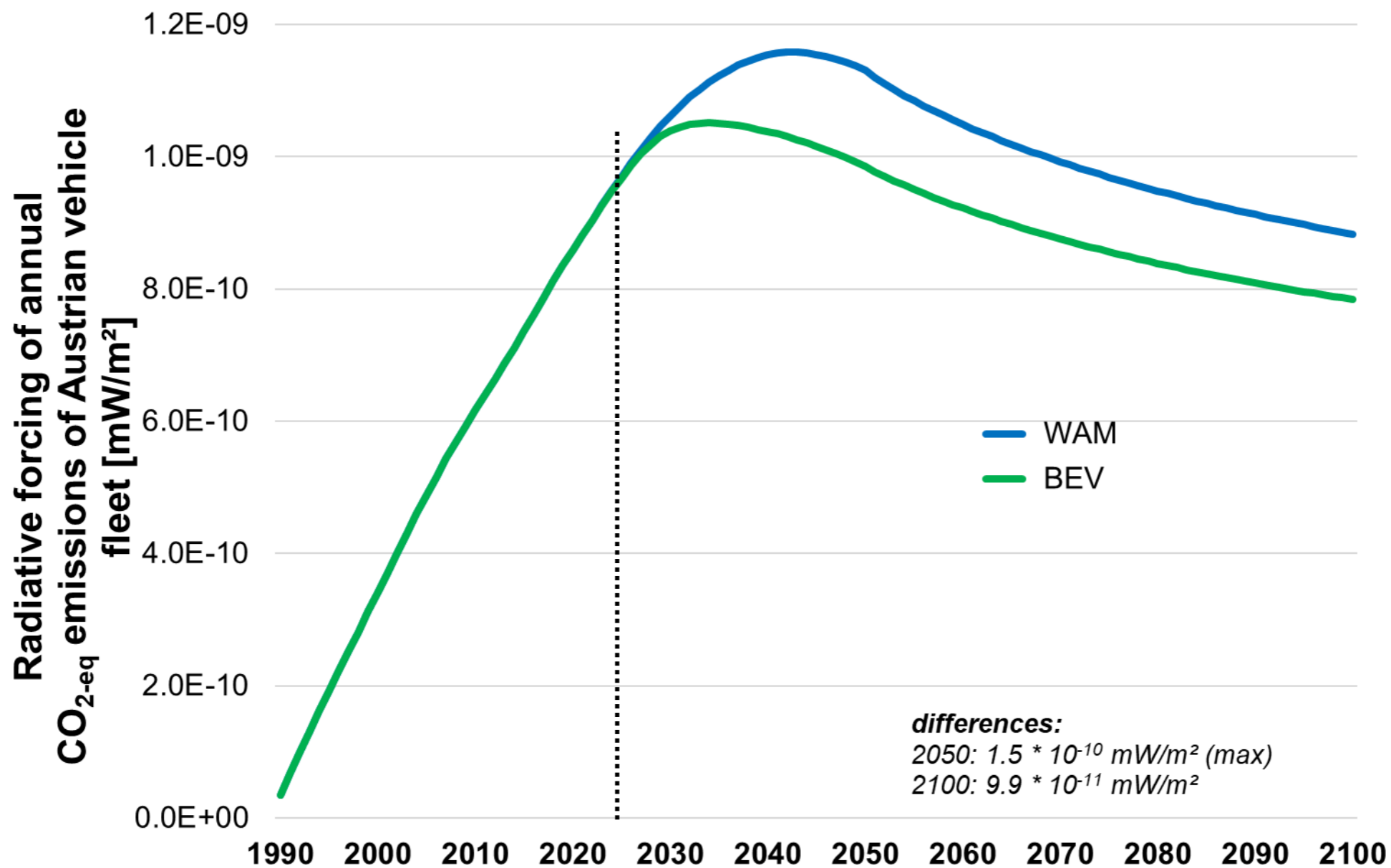


# LCA basierte THG-Emissionen der Fahrzeugflotte

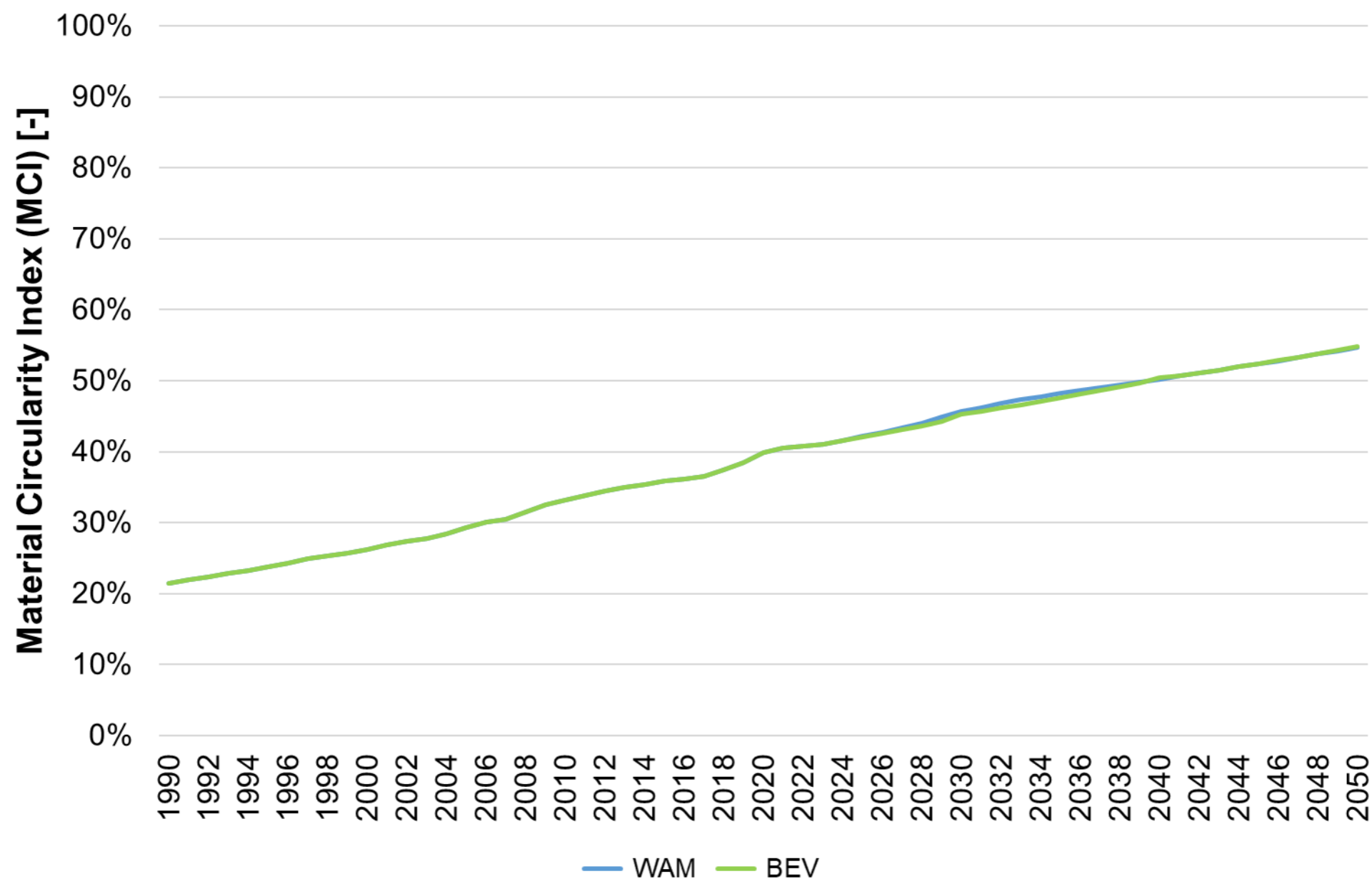
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# Radiative Forcing of the Two Scenarios

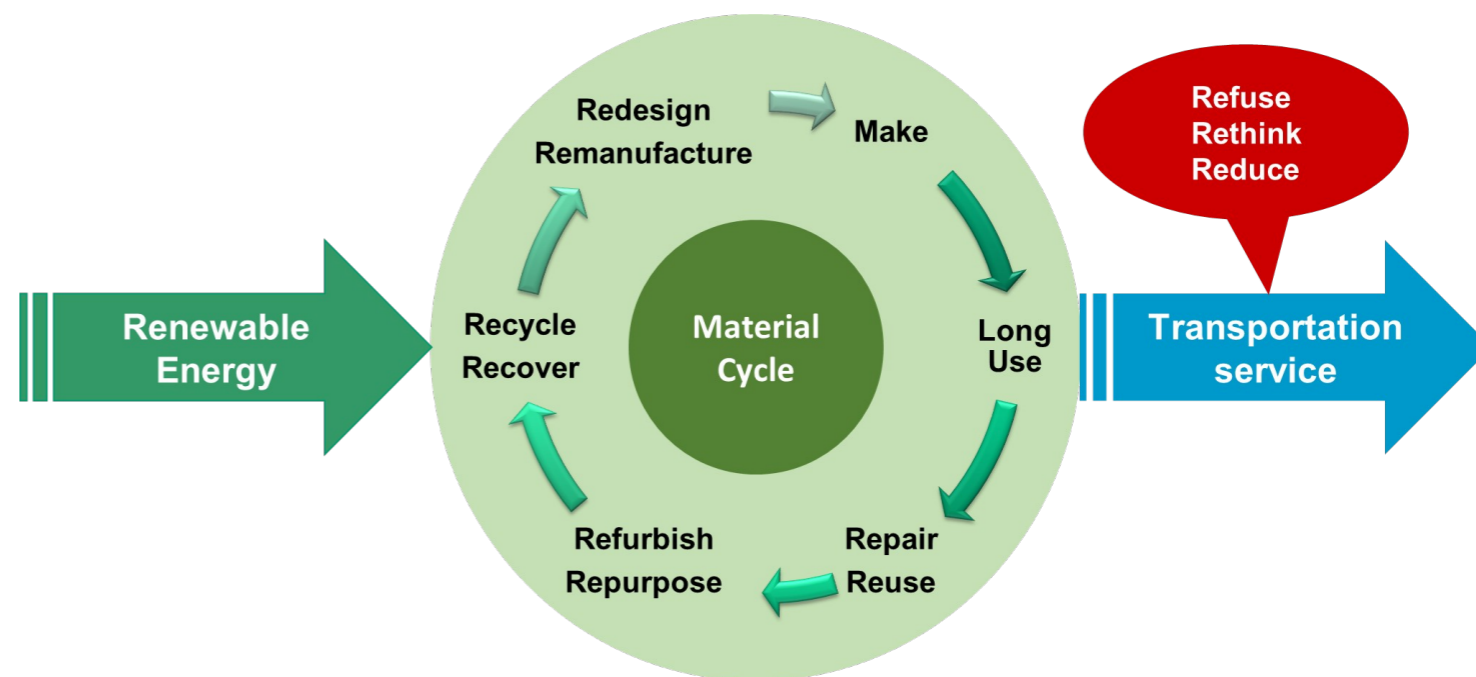


# Material Circularity Index of Austria Vehicle Fleet 1990 - 2050



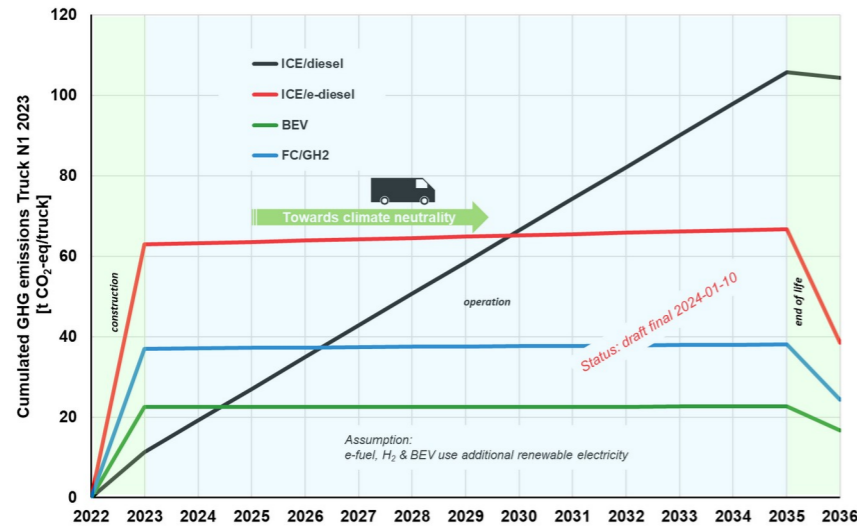
# Conclusions

- **Climate Neutrality Potential** and **Circularity Potential** are two new assessment categories using dynamic Life Cycle Assessment
- A **product / service** is „climate neutral“ and „circular“, if its whole life cycle - production, operation and end-of-life
  - **uses only**
    - reused components
    - secondary (recycled) material
    - renewable energy
  - **makes**
    - zero waste and
    - zero GHG emissions
- **Climate Neutrality** and **Circularity** are **visionary and long term targets**
  - **BUT**: future products and services must be developed and assessed „**towards**“ **Climate Neutrality** and **Circularity**

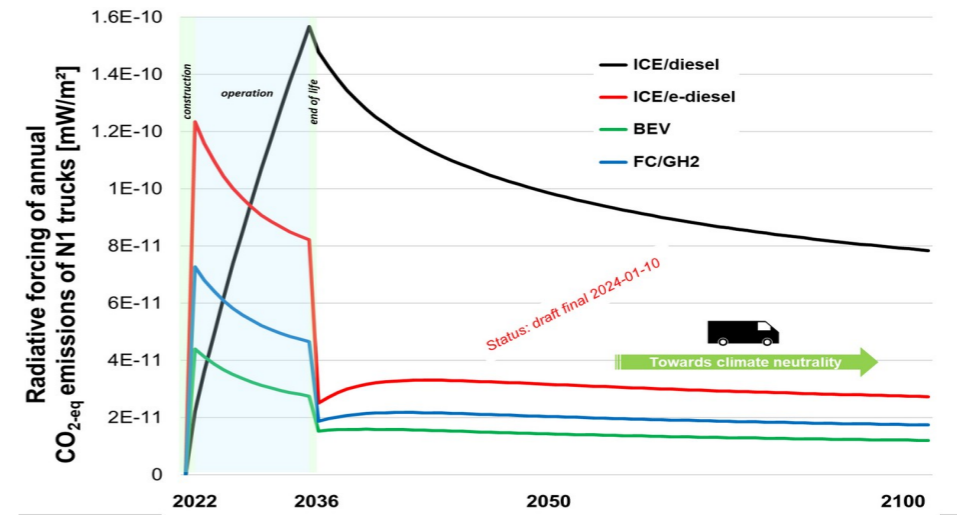


# Time Matters for Climate Neutrality and Circularity

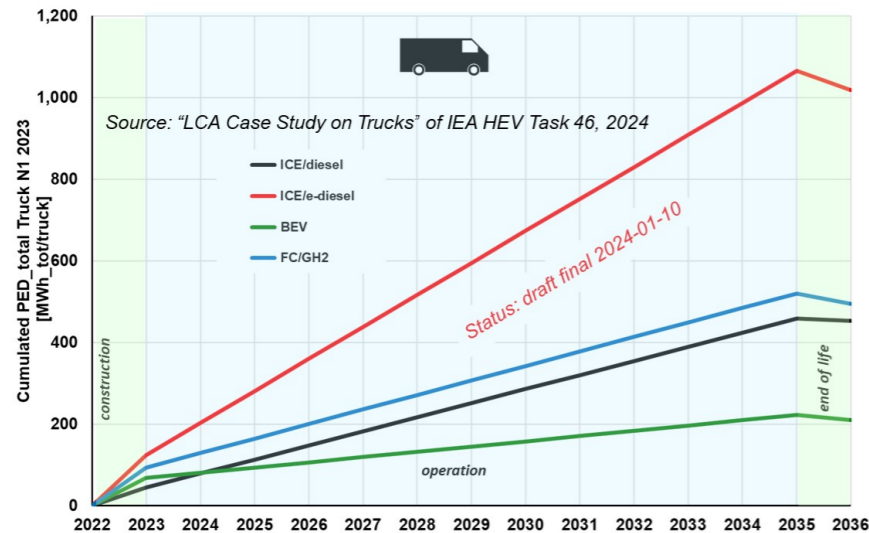
## GHG Emissions



## Climate Neutrality Potential



## Primary Energy Demand



## Circularity Potential

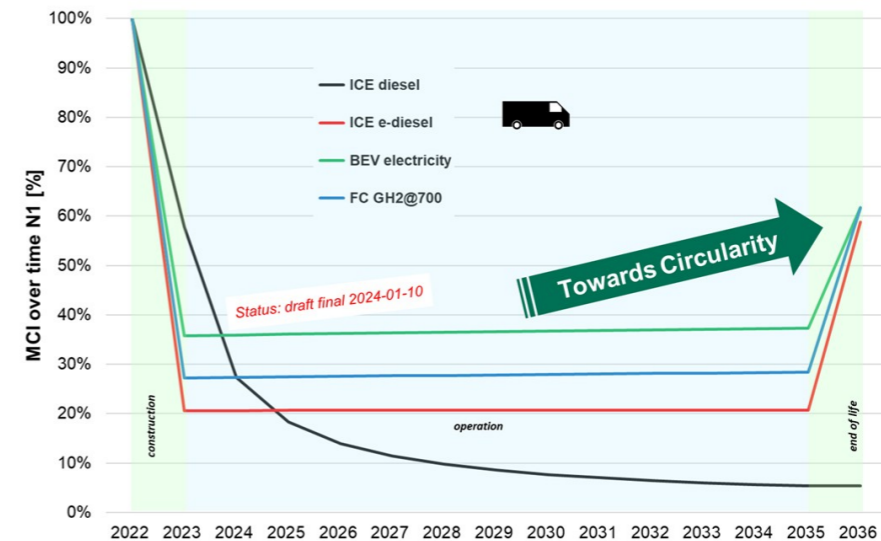




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<https://ieahev.org/tasks/46/>