

# Life cycle greenhouse gas emissions of future power systems in the context of 2 °C

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# “Amazingly low carbon footprints” (media coverage)



Source: <https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints>

# Life cycle assessment (LCA)

## LCA attributes emissions to products

- 1) Considering emissions over the life cycle
  - Production, use, end-of-life
- 2) Considering emissions in production networks
  - Resource extraction, manufacturing, etc.

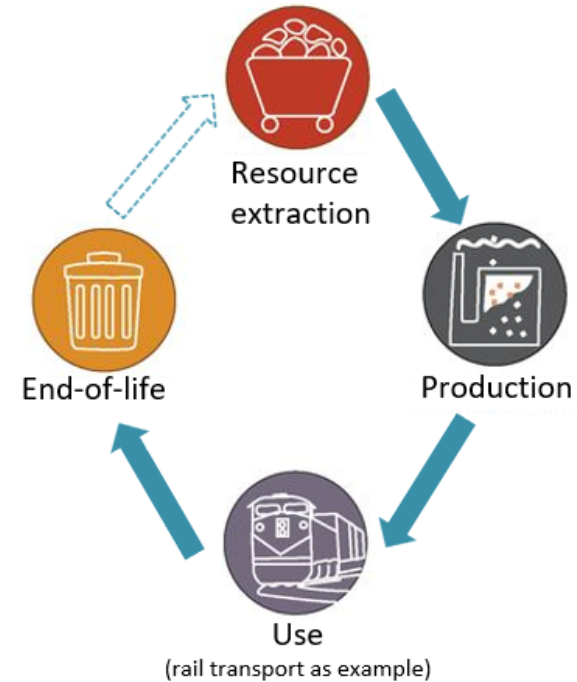


Figure: Adapted from Hellweg & Mila i Canals (2014)

# LCA in a 2 °C context

- NTNU and partners has built a future-oriented LCA model, THEMIS — Incorporating future technological progress

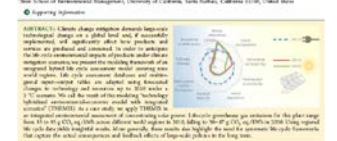
- In the current work, coefficients derived from THEMIS were implemented into the energy scenario model REMIND — Operated by Potsdam Institute for Climate Impact Research
- By default, REMIND does not systematically account for indirect, or life cycle, emissions

**Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies**  
 Edgar G. Hertwich<sup>1</sup>, Thomas Albrecht<sup>2</sup>, Juan A. Rosendal<sup>3</sup>, Anders Arnesen<sup>4</sup>, Sørensen Kurt<sup>5</sup>, Karin A. Haugen<sup>6</sup>, Joseph R. Boyland<sup>7</sup>, Anders Ravnung<sup>8</sup>, Michael Vogel<sup>9</sup>, and Lutz G. Jansen<sup>10</sup>

**Abstract:** Integrated life-cycle assessment (ILCA) of electricity supply scenarios shows that low-carbon technologies (LCTs) have a significant environmental benefit compared to fossil-based technologies (FBTs) in terms of global warming potential (GWP), acid equivalent potential (AEP), and particulate matter (PM) emissions. The benefit of LCTs is most pronounced when considering the full life cycle, including the production and distribution of the technologies themselves. This benefit is most pronounced when considering the full life cycle, including the production and distribution of the technologies themselves. This benefit is most pronounced when considering the full life cycle, including the production and distribution of the technologies themselves.

**1. INTRODUCTION**  
 A 2 °C global energy transition requires a dramatic shift in the global energy system. This shift requires a combination of energy efficiency improvements and a decrease in fossil energy use. The energy transition is a complex task that requires a combination of energy efficiency improvements and a decrease in fossil energy use. The energy transition is a complex task that requires a combination of energy efficiency improvements and a decrease in fossil energy use.

**ENVIRONMENTAL Science & Technology**  
**A Methodology for Integrated, Multiregional Life Cycle Assessment Scenarios under Large-Scale Technological Change**  
 Thomas Albrecht<sup>1</sup>, Sørensen Kurt<sup>2</sup>, Anders Arnesen<sup>3</sup>, Joseph R. Boyland<sup>4</sup>, Karin A. Haugen<sup>5</sup>, and Edgar G. Hertwich<sup>6</sup>  
 Theorizing Energy Programme and Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, 7007, Norway



**ABSTRACT:** Scenario-based integrated multiregional life cycle assessment (ILCA) of electricity supply scenarios shows that low-carbon technologies (LCTs) have a significant environmental benefit compared to fossil-based technologies (FBTs) in terms of global warming potential (GWP), acid equivalent potential (AEP), and particulate matter (PM) emissions. The benefit of LCTs is most pronounced when considering the full life cycle, including the production and distribution of the technologies themselves.

**Environmental Modelling & Software**  
**Deriving life cycle assessment coefficients for application in integrated assessment modelling**  
 Anders Arnesen<sup>1</sup>, Gunnar Loken<sup>2</sup>, Malaja Feld<sup>3</sup>, Benjamin Leon Boddeke<sup>4</sup>, Edgar G. Hertwich<sup>5</sup>

**Abstract:** The need for life cycle assessment (LCA) coefficients for application in integrated assessment modelling (IAM) is increasing. This paper presents a methodology for deriving LCA coefficients for application in IAM. The methodology involves a combination of LCA and IAM modelling. The methodology involves a combination of LCA and IAM modelling.

**1. Introduction**  
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**ARTICLES**  
**Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling**  
 Michael Pahle<sup>1</sup>, Anders Arnesen<sup>2</sup>, Florian Hampel<sup>3</sup>, Alexander Poppi<sup>4</sup>, Edgar G. Hertwich<sup>5</sup>, and Gernot Luderer<sup>6</sup>

**Abstract:** This paper presents a methodology for understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling. The methodology involves a combination of LCA and IAM modelling. The methodology involves a combination of LCA and IAM modelling.

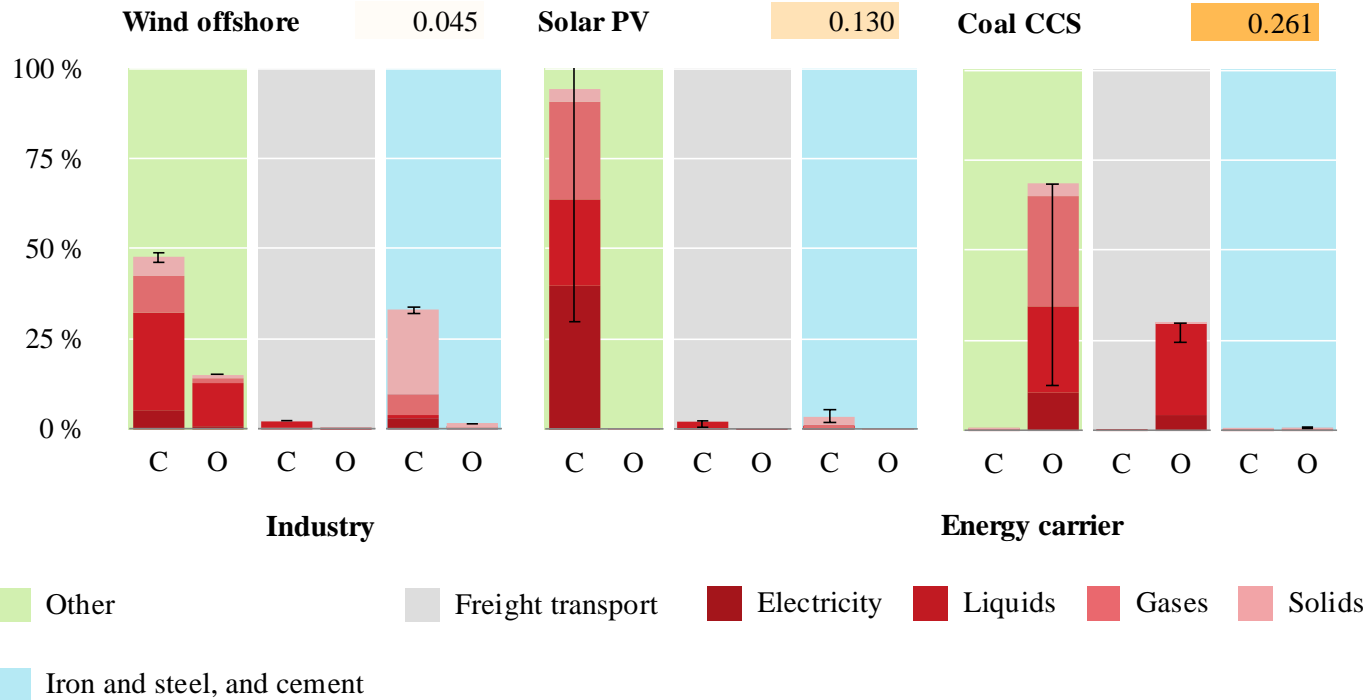
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# Introducing LCA in energy scenario modelling



- Step 1: Derive energy coefficients from LCA and organize the coefficients in a carefully chosen way
- Step 2: Implement the coefficients from Step 1 in the energy scenario model REMIND
- Step 3: Analyse life cycle emissions of global electricity supply in the context of 2 °C
- We capture technological progress and regional variation
  - In the energy technologies themselves
  - In the technologies used to supply energy and materials
- We achieve harmonization of parameter data

# Example of LCA energy coefficients derived for use in scenario modelling (i.e., Step 1)

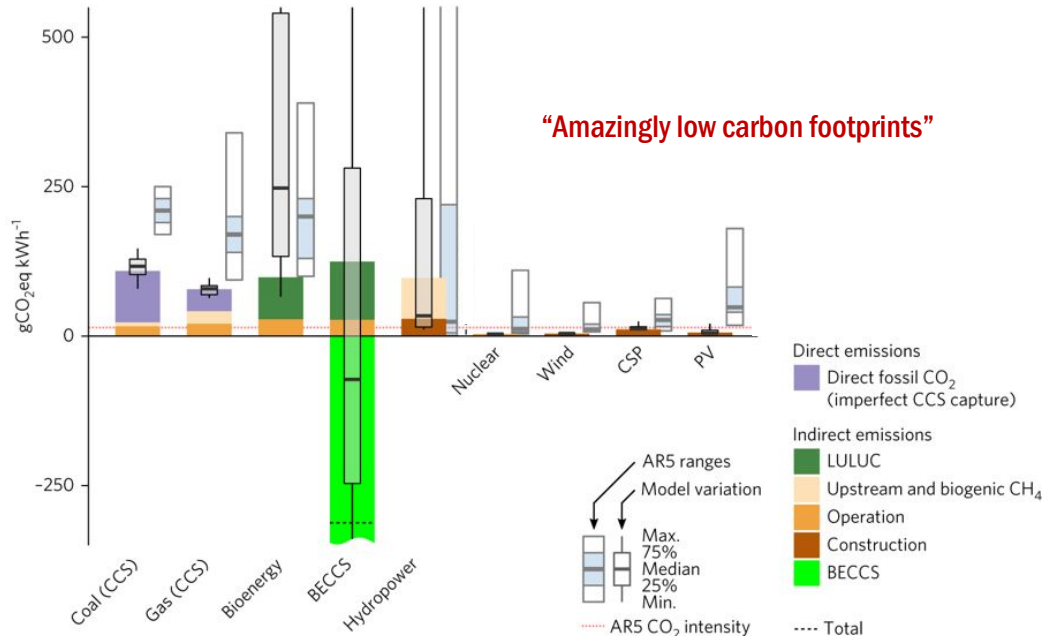


Distinguish:

- Construction (C) and operation (O)
- Energy carrier (stacked column categories)
- Industry (background colour)
- Region (not shown in figure)
- Year (not shown in figure)

Source: Arvesen et al. (2018)

# Life cycle greenhouse gas emissions in 2050 in REMIND

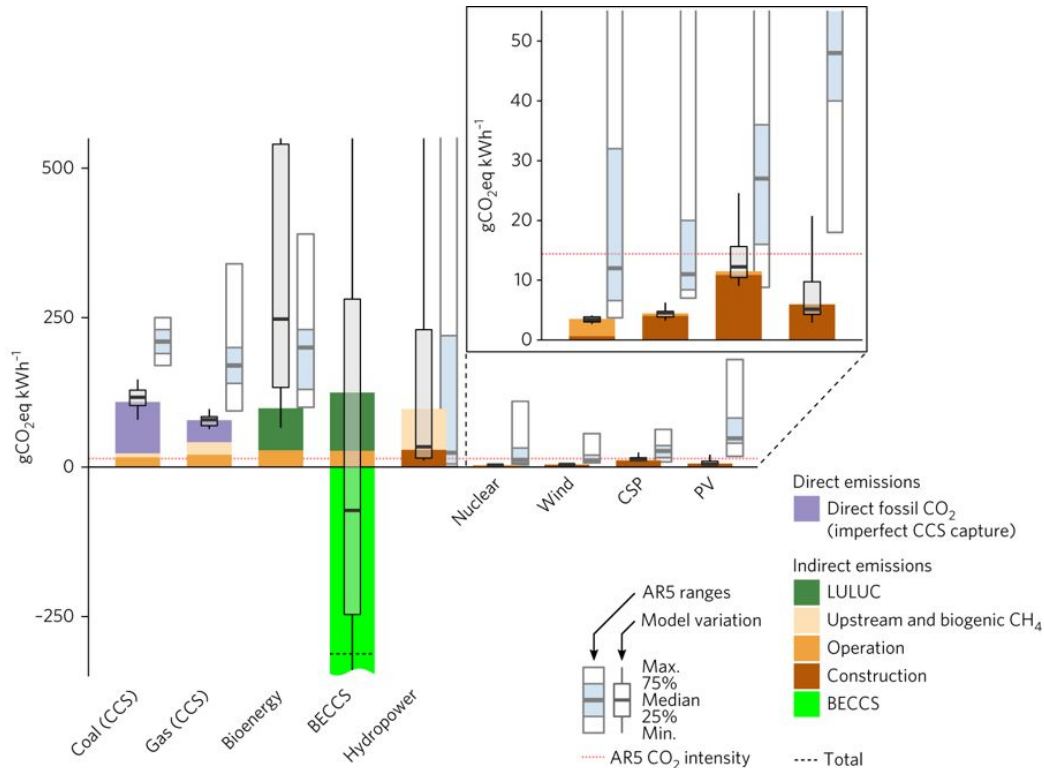


In a 2 °C world in 2050 (these are global averages):

- Nuclear, wind and solar PV: 4-6 g CO<sub>2</sub>e kWh<sup>-1</sup>
- Hydro and bioenergy: ~ 100 g CO<sub>2</sub>e kWh<sup>-1</sup> (very uncertain)
- Coal and gas with CO<sub>2</sub> capture: ~ 100 g CO<sub>2</sub>e kWh<sup>-1</sup>

Figure: Pehl et al. (2017)

# Life cycle greenhouse gas emissions in 2050 in REMIND



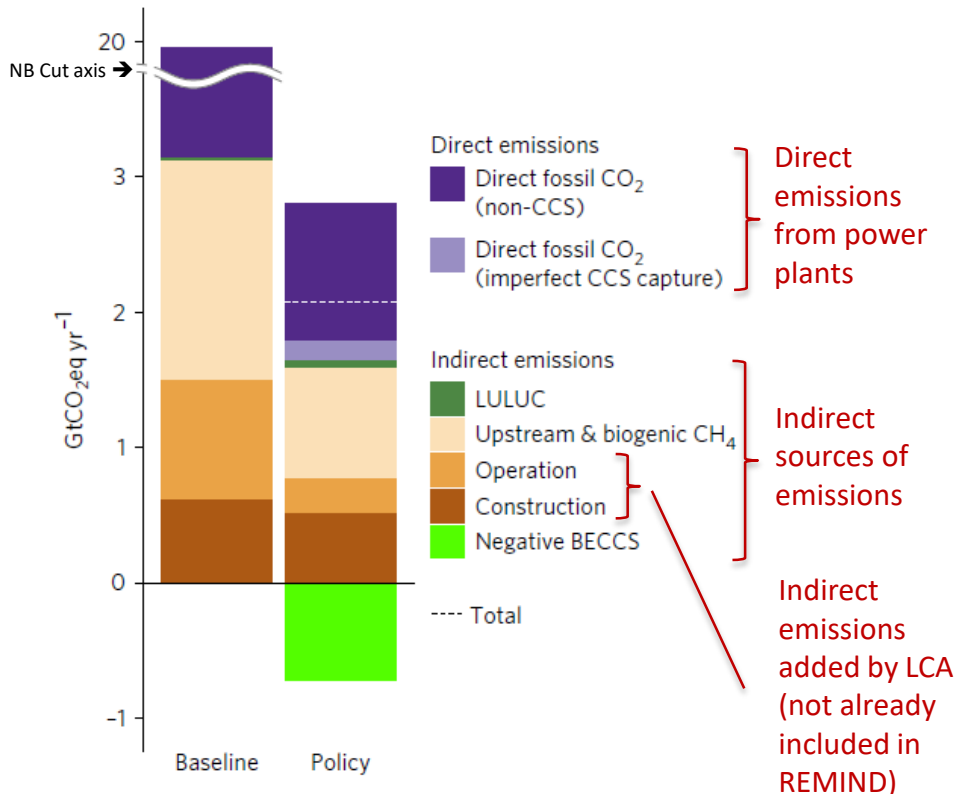
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Figure: Pehl et al. (2017)



# Total global 2050 life cycle emissions in REMIND



- Indirect emissions are small
  - Compared to 2050 Baseline direct emissions
  - And compared to current real-world direct emissions
- At the same time: Indirect emissions are important in relative terms in the climate policy scenario in 2050
- REMIND already accounts for the most important indirect sources of emissions
- Life cycle emissions can influence optimal technology choice, but not by much in this case:
  - In response to indirect emissions added by LCA, REMIND changes (only) 4% of technology selections

Source: Pehl et al. (2017)

# Final remarks



- **Indirect emissions can influence optimal selections of technologies**
  - We investigate this influence for the power sector, and find that it is fairly small
  - It is potentially more significant for other sectors, for example transport
- **What LCA may contribute to energy scenario modelling:**
  - Consistent treatment of indirect emissions of technologies
  - Identification of environmental win-win relationships or trade-offs looking at other impact categories than climate change (in other papers, under review)



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## The research

- Arvesen, A., Luderer, G., M. Pehl, B.L. Bodirsky, E.G. Hertwich. 2018. Deriving life cycle assessment coefficients for application in integrated assessment modelling. *Environmental Modelling & Software* 99(1):111-125
- Pehl, M., Arvesen, A., Humpenöder, F., Popp, A., Hertwich, E.G., Luderer, G., 2017. Understanding future emissions from low-carbon power systems by integration of life cycle assessment and integrated energy modelling. *Nature Energy* 2: 939-945
- The LCA coefficients and an R script for using the coefficients in scenario analysis are available at: <http://www.fp7-advance.eu/content/environmental-impacts-module>

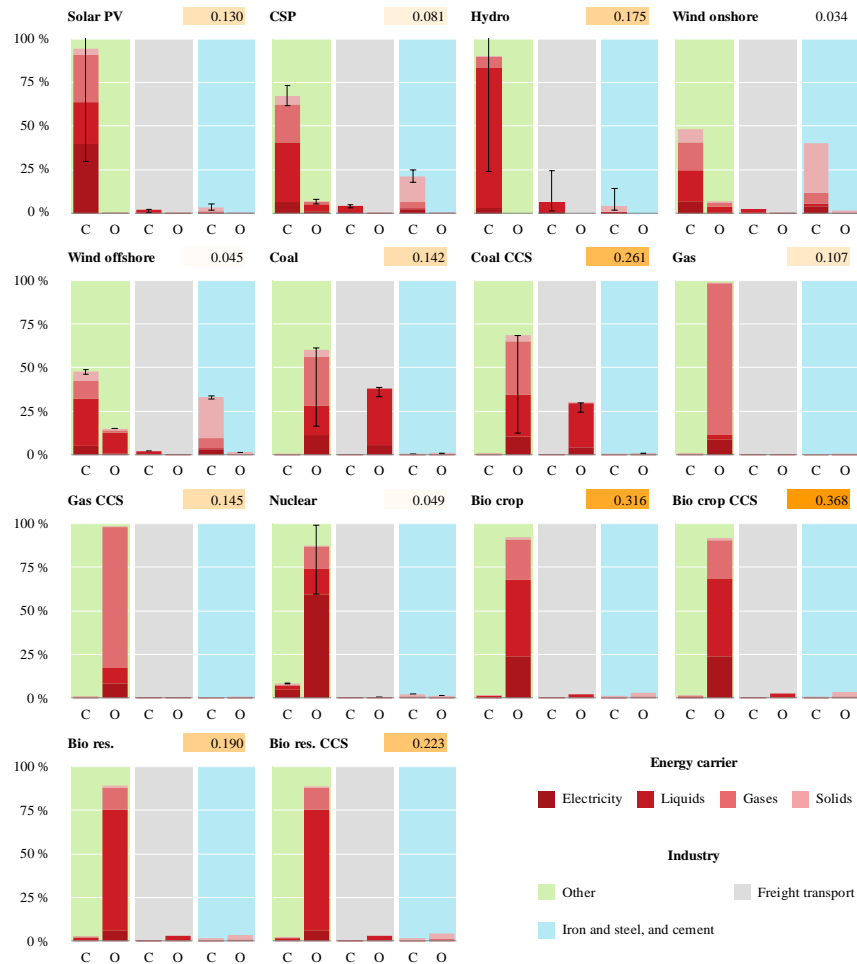
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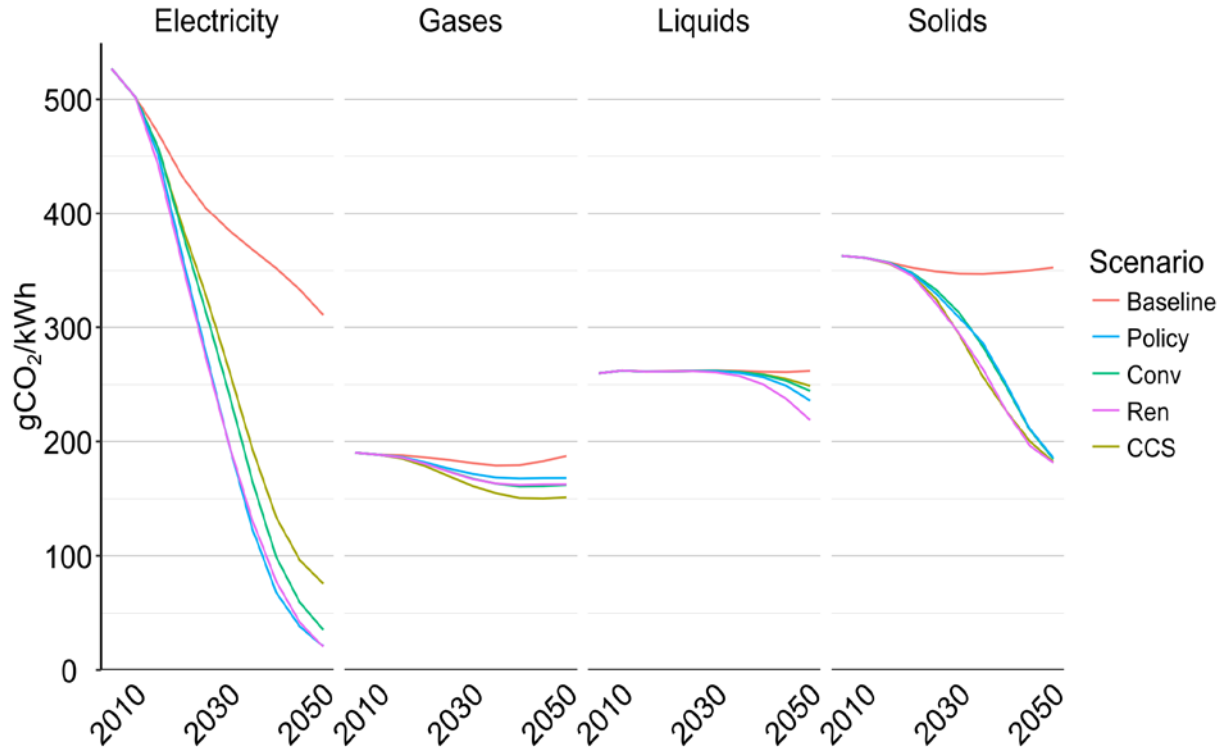


Extra



Source: Arvesen et al. (2018)

# CO2 intensities in REMIND



Source: Pehl et al. (2017) (supplementary)