Integrating LCAs with scenarios for assessing technology change on a global level

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Agenda

1) THEMIS LCA model framework
2) Vintage capital modelling approach for global-scale LCA
3) Introducing LCA in a energy-economy model

THEMIS

- Integrated hybrid LCA model framework
- Described by Gibon et al. (2015)
- Used in report by UNEP International Resource Panel (Hertwich et al. 2016)
- Mainstream databases (Ecoinvent, EXIOBASE) with adaptations for world regions

Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies

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Decarbonization of electricity generation can support climate-change mitigation and presents an opportunity to address pollution resulting from fossil-fuel combustion. Generally, renewable technologies require higher
than fossil-based power sy
increased up-front emissions
we present, to our knowled
cycle assessment (LCA) of long
electricity generation from r
and solar thermal, wind, and
capture and storage for fos
emissions causing particulat
toxicity, freshwater eutroph
climate-change-mitigation (
(Baseline) scenarios of the
2050. We use a vintage stock
installed capacity year-by-ye
for changes in the energy mi
plants. Under the Baseline s
pollutants more than double
gies introduced in the BLUE
electricity supply while stab
Material requirements per u
nologies can be higher than
11–40 times more copper f
times more iron for wind pov
of current global copper an
suffice to build a low-carbon
the world's electricity needs

land use | climate-change mitigat
multiregional input–output | CO₂

A shift toward low-carbon
to be an essential ele
strategies (1, 2). Much resea
technologies to reduce clima
of these technologies (2–4).
of individual technologies su
carbon power plants tend to
fueled plants and might the
other environmental impact
about the environmental in
shift to a low-carbon electric
material and construction re
be large relative to current
shift to low-carbon electricity
types of pollution? Energy
represent the manufacturin
technologies and are theref

questions. LCAs typically address a single technology at a time. Comparative studies often focus on a single issue, such as selected pollutants (7), or the use of land (8) or metals (9, 10).

GREEN ENERGY CHOICES:
THE BENEFITS, RISKS
AND TRADE-OFFS OF
LOW-CARBON TECHNOLOGIES
FOR ELECTRICITY PRODUCTION

A Methodology for Integrated, Multiregional Life Cycle Assessme
Scenarios under Large-Scale Technological Change

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Ⓢ *Supporting Information*

ABSTRACT: Climate change mitigation demands large-scale technological change on a global level and, if successfully implemented, will significantly affect how products and services are produced and consumed. In order to anticipate the life cycle environmental impacts of products under climate mitigation scenarios, we present the modeling framework of an integrated hybrid life cycle assessment model covering nine world regions. Life cycle assessment databases and multiregional input–output tables are adapted using forecasted changes in technology and resources up to 2050 under a 2 °C scenario. We call the result of this modeling "technology hybridized environmental-economic model with integrated scenarios" (THEMIS). As a case study, we apply THEMIS in an integrated environmental assessment of concentrating solar power. Life-cycle greenhouse gas emissions for this plant ra
from 33 to 95 g CO_2 eq./kWh across different world regions in 2010, falling to 30–87 g CO_2 eq./kWh in 2050. Using regio
life cycle data yields insightful results. More generally, these results also highlight the need for systematic life cycle framewo
that capture the actual consequences and feedback effects of large-scale policies in the long term.

1. INTRODUCTION

A 2 °C global average temperature increase is considered the threshold above which global warming consequences on human health, ecosystems, and resources might be disastrous. Pathways incorporating a combination of a shift toward low-carbon energy technologies, efficiency improvements, and a decrease in final consumption present various ways to reduce greenhouse gas emissions as means to reach climate targets. In effect, climate change mitigation demands large-scale technology change on a global level and, if successful, will significantly

generation through transportation to cement production
therefore essential to assess these modifications based
model that contains all life cycle phases of both existin
emerging technologies.

Extending LCA to future scenarios is an arguably eff
way to understand the implications of long-term change
as those planned in climate change mitigation roadmaps
review of LCA methodology, Guinée et al.[1] argue: "It m
more realistic [than microscopic consequential product L
to start thinking how more realistic, macroscopic scenari

THEMIS technology change and variation

- Electricity mix employed depends on region, scenario and year

- Electricity supply technologies
  - Variations in key parameters (e.g., efficiency, load factors, emission factors)
  - Successive technology generations (e.g., poly-Si ➔ thin-film PV)

- For selected materials production
  - Aluminium, copper, nickel, iron and steel, metallurgical grade silicon, flat glass, zinc and clinker
  - Reduced emission intensities, increased efficiencies of

Gibon et al. 2015; Hertwich et al. 2016

Vintage capital modelling approach

- To address impacts of future scenarios on large scales
  - Capture timing of activities: attributing construction, operation and end-of-life activities to appropriate years
  - Analyse activities with technology data pertaining to appropriate years
  - Capture basic transition dynamics (if present)

- Key elements of approach
  - Tracking of capacity additions and operating capacity
  - Consider distribution of emissions by life cycle stages
  - Consider replacement at end-of-life
  - From THEMIS: life cycle inventories as functions of time

Arvesen and Hertwich 2011; Hertwich et al. 2015; Arvesen et al., under review

Matrix-based computation

$$\boldsymbol{y}_{t,r,\tau,s,p} = \varphi_{t,r,\tau,s,p} \cdot \left(\boldsymbol{A}_{\tau,s} \cdot \boldsymbol{y}^{fd}_{t,r,\tau,s} \cdot \boldsymbol{b}^{phase}_{\tau,s,p} \right) \quad , \quad t \in T, \;\; \mathrm{r} \in R, \;\; \tau \in \mathrm{T}, \;\; s \in S, \;\; p \in P$$

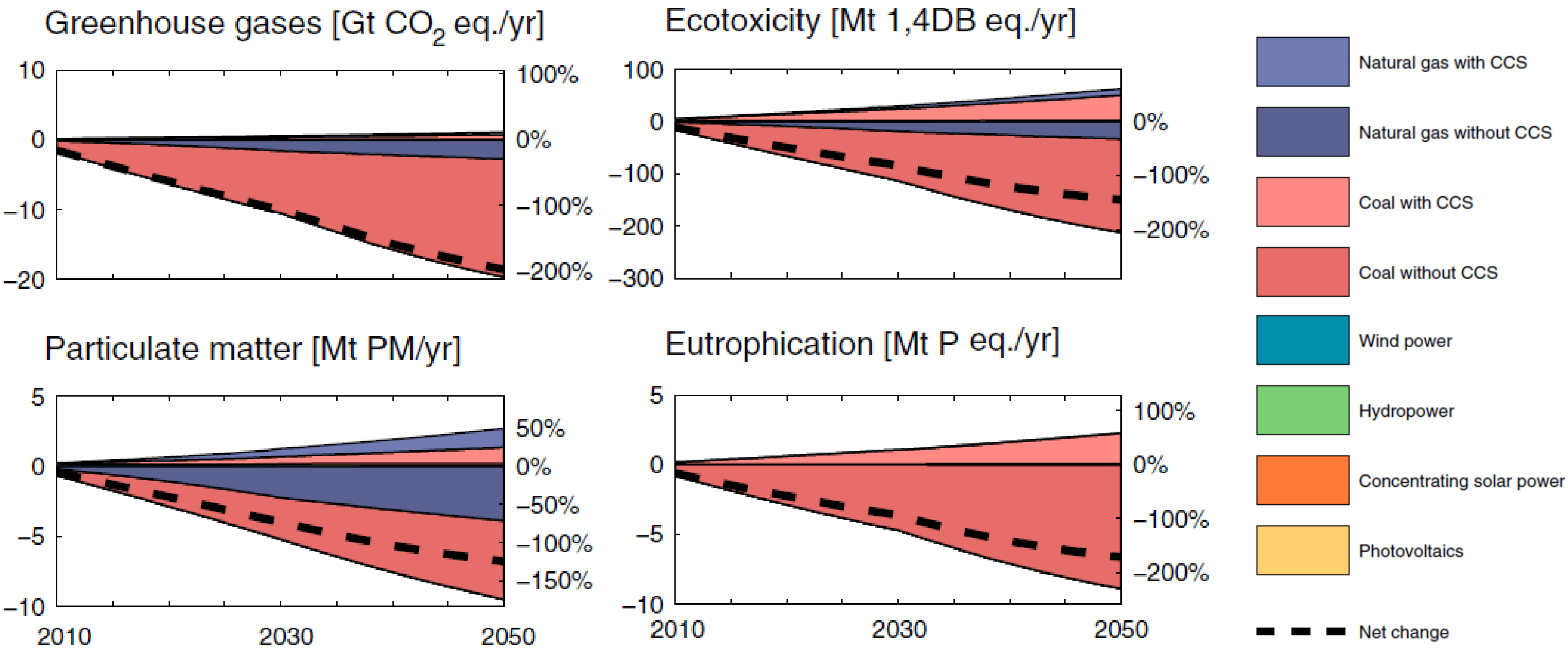
$$\boldsymbol{x}_{t,r,\tau,s,p} = (\boldsymbol{I} - \boldsymbol{A}_{\tau,s})^{-1} \cdot \boldsymbol{y}_{t,r,\tau,s,p} \quad , \quad t \in T, \;\; \mathrm{r} \in R, \;\; \tau \in \mathrm{T}, \;\; s \in S, \;\; p \in P$$

$$\left.\begin{aligned}
\boldsymbol{x}^{\oplus}_{t,r,\tau,p=cons,s} &= \boldsymbol{x}_{t,r,\tau,p=cons,s} \cdot \left(K^{new}_{t,r,\tau,s} + \alpha \cdot K^{repl}_{t,r,\tau,s} \right) \\
\boldsymbol{x}^{\oplus}_{t,r,\tau,p=oper,s} &= \boldsymbol{x}_{t \in T^{K},r,\tau,p=oper,s} \cdot K^{exist}_{t \in T^{K},r,\tau,s} + \boldsymbol{x}_{t \in T^{U},r,\tau,p=oper,s} \cdot U^{exist}_{t \in T^{U},r,\tau,s} \\
\boldsymbol{x}^{\oplus}_{t,r,\tau,p=eol,s} &= \boldsymbol{x}_{t,r,\tau,p=eol,s} \cdot K^{decom}_{t,r,\tau,s}
\end{aligned}\right\} \quad , \quad t \in T, \;\; \mathrm{r} \in R, \;\; \tau \in \mathrm{T}, \;\; s \in S$$

$$\overline{\boldsymbol{x}}^{\oplus}_{\tau,s} = \sum_{t \in T} \sum_{r \in R} \sum_{p \in P} \boldsymbol{x}^{\oplus}_{t,r,\tau,p,s} = \sum_{t \in T} \sum_{r \in R} \left(\boldsymbol{x}^{\oplus}_{t,r,\tau,p=cons,s} + \boldsymbol{x}^{\oplus}_{t,r,\tau,p=oper,s} + \boldsymbol{x}^{\oplus}_{t,r,\tau,p=eol,s} \right) \quad , \quad \tau \in \mathrm{T}, \;\; s \in S$$

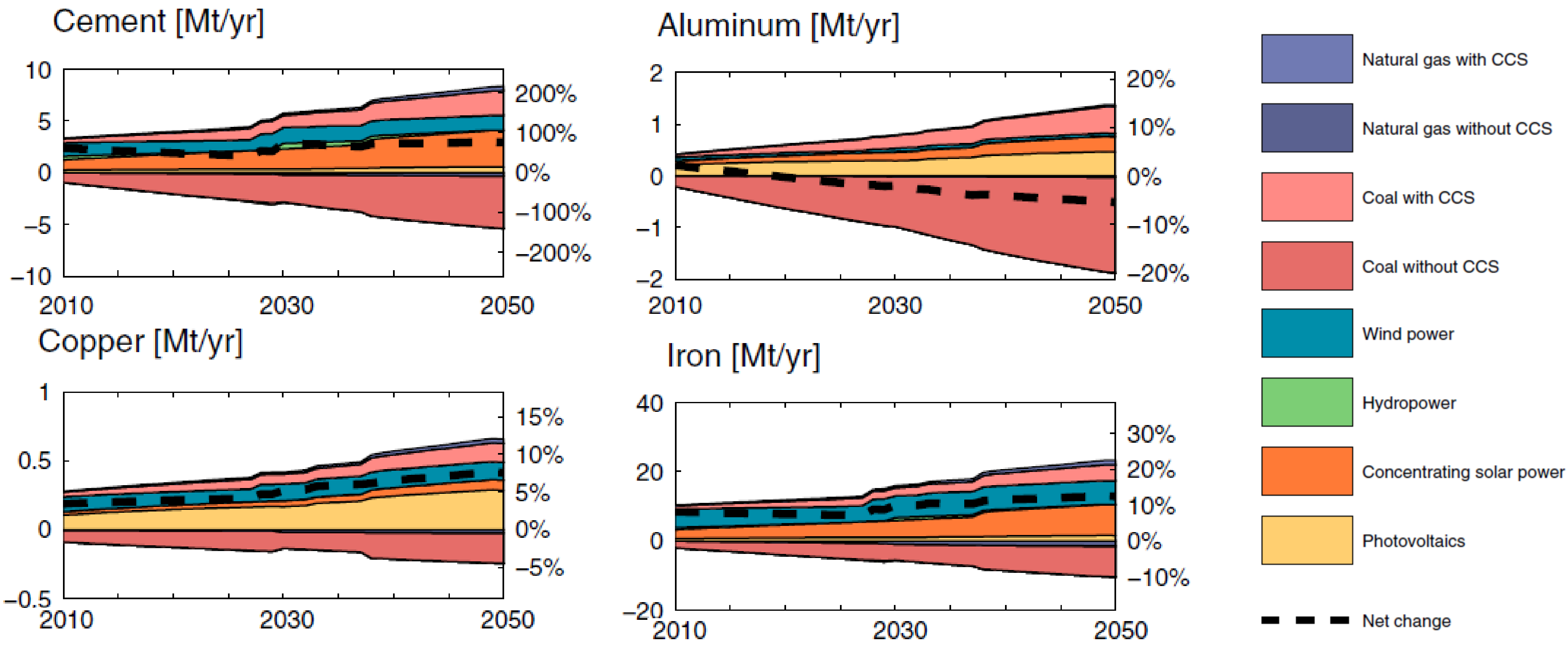
Arvesen et al., (under review)

Net impacts of mitigation instead of baseline (mitigation - baseline) for global electricity suppl



Hertwich et al. (2015)

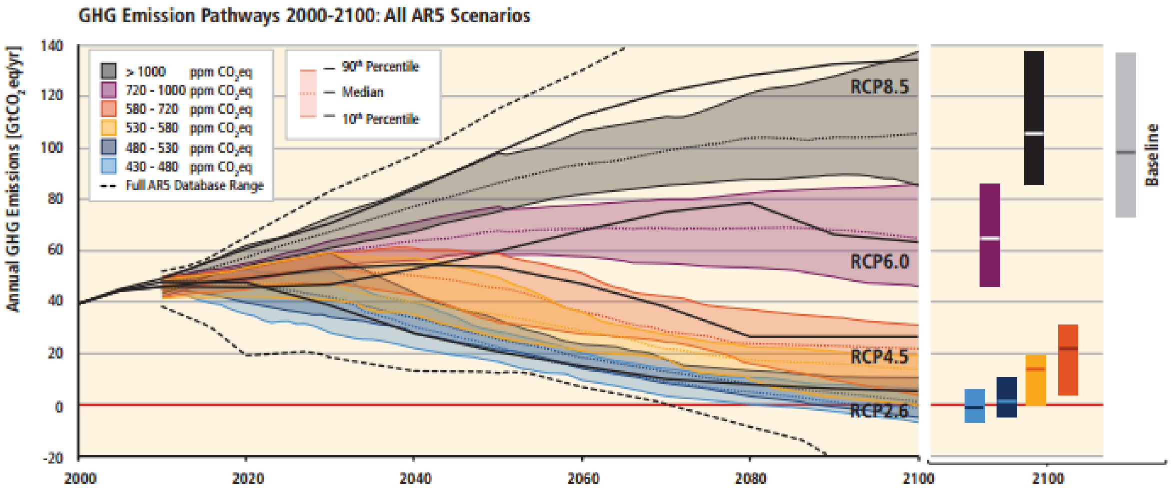
Net impacts of mitigation instead of baseline (mitigation - baseline) for global electricity supply



Hertwich et al. (2015)

Introducing LCA in energy-economy models

- Collaboration under ADVANCE EU project
  - Potsdam Institute for Climate Impact Research, operating the model REMIND
  - Norwegian University of Science and Technology, operating THEMIS

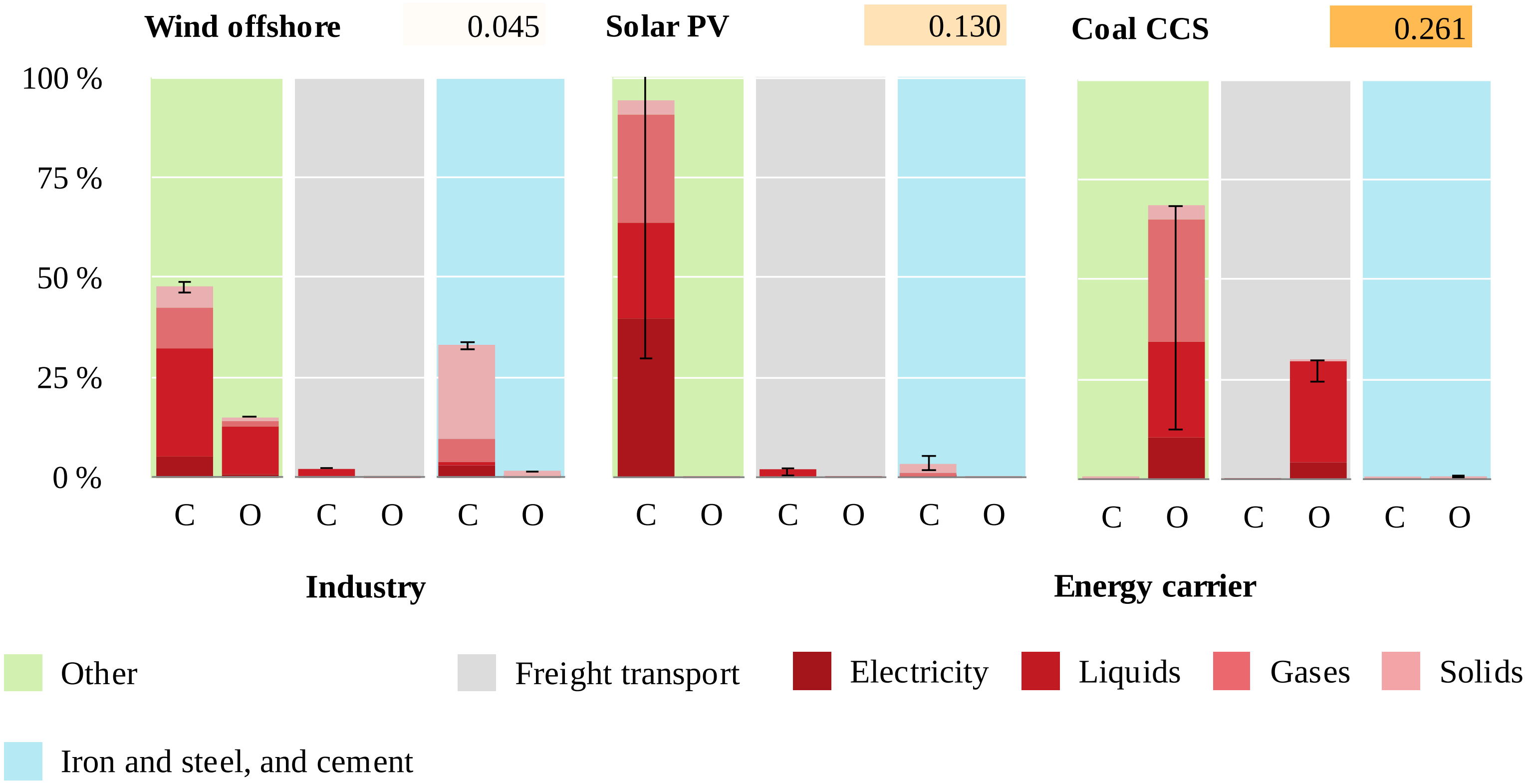


widely used, e.g.

Figure: IPCC AR5-WGIII

Preliminary results

LCA energy data for use in energy-economy models



Distinguish:

- Construction (C) and operation (O)
- Energy carrier (stacked column categories)
- Emission source (background colour)

Arvesen et al. (under review)

Matrix-based computation

$$\boldsymbol{y}_{t,r,\tau,s,p} = \boldsymbol{\varphi}_{t,r,\tau,s,p} \cdot \left(\widehat{\boldsymbol{A}_{\tau,s} \cdot \boldsymbol{y}^{fd}_{t,r,\tau,s}} \cdot \boldsymbol{b}^{phase}_{\tau,s,p} \right)$$

$$\boldsymbol{x}_{t,r,\tau,s,p} = (\boldsymbol{I} - \boldsymbol{A}_{\tau,s})^{-1} \cdot \boldsymbol{y}_{t,r,\tau,s,p}$$

$$\boldsymbol{d}^{cec,tot}_{t,r,\tau,s,p} = \boldsymbol{C}^{cec,tot}_{\tau,s} \cdot \boldsymbol{x}_{t,r,\tau,s,p}$$

$$\boldsymbol{E}^{ec,dir}_{t,r,\tau,s,p} = \boldsymbol{A}^{ec}_{\tau,s} \cdot \widehat{\boldsymbol{x}_{t,r,\tau,s,p}} \cdot \boldsymbol{B}^{ind}_{\tau,s}$$

$$\boldsymbol{D}^{cec,dir}_{t,r,\tau,s,p} = \boldsymbol{C}^{cec,dir}_{\tau,s} \cdot \boldsymbol{E}^{ec,dir}_{t,r,\tau,s,p}$$

$$\boldsymbol{d}^{cec,res}_{t,r,\tau,s,p} = \boldsymbol{d}^{cec,tot}_{t,r,\tau,s,p} - \boldsymbol{D}^{ec,dir}_{t,r,\tau,s,p} \cdot \boldsymbol{1}$$

$$\tilde{\boldsymbol{D}}^{cec,dir}_{t,r,\tau,s,p} = \boldsymbol{D}^{cec,dir}_{t,r,\tau,s,p} \circ \boldsymbol{x}^{ind}_{t,r,\tau,s,p}$$

- Energy accounting approach of Arvesen and Hertwich (2015)
- Material accounting approach of Singh et al. (2015)

Arvesen et al. (under review)

Global scenario results for 2050 from REMIND

Content removed from presentation slides distributed online

Pehl et al. (under review)

Impact on optimal technology choice

Content removed from presentation slides distributed online

Pehl et al. (under review)

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