LCA OF ELECTRICITY GENERATION TECHNOLOGIES

UNECE modelling activities – Carbon neutrality project

01.07.2021
Starting point: UNEP IRP report “Green Energy Choices”

Life cycle assessment (LCA) of electricity production technologies

Coal, natural gas, with and without CCS
Hydropower
Wind power
Concentrating solar power
Photovoltaic power
Geothermal power

Impact assessment over 2010-2050 period

Two IEA scenarios (Baseline, Blue Map) and 9 world regions
Starting point: UNEP IRP report “Green Energy Choices”

Limitations

Absence of state-of-the-art nuclear power and biomass

==> need for expertise on these technologies

Optimistic efficiencies?

Limited consideration of methane leakage in fossil fuel extraction

No direct emissions in hydropower

No consistent end-of-life treatment consideration across technologies

Energy scenarios outdated: use REMIND? MESSAGE? …?

Update welcome!

Most data is 10 years

Add newer technologies (namely small modular reactors)
TECHNOLOGIES

Full list

Photovoltaics
- Polycrystalline silicon, ground-/roof-mounted
- CIGS, ground-/roof-mounted
- CdTe, ground-/roof-mounted

CSP
- Trough
- Tower

Coal
- Existing PC, with and without CCS
- Integrated gasification CC, with and without CCS
- Coal SCPC, with and without CCS

Gas
- NGCC, with and without CCS

Hydropower
- 660 and 360 MW designs

Wind
- Onshore
- Offshore, concrete and steel foundation

Nuclear power
- Boiling water reactor
- Pressure water reactor (average global reactor)
**REGIONS**

**Why regionalizing?**

Data representativeness

Electricity mixes can be systematically adapted to region, year, and a given scenario (with REMIND “Base SSP2” as baseline), as well as a few other processes (cement...)

**Adapting load factors to regional climate conditions**

Solar irradiation

Wind regimes

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**REMIND regions**

<table>
<thead>
<tr>
<th>Region</th>
<th>Code</th>
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<tr>
<td>Canada, Australia &amp; New Zealand</td>
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</table>
Results normalized & weighted, Europe EU region

"impact assessment categories should be selected depending on their contribution to the normalised and weighted results of the analysis"
### List of retained indicators, following EC recommendations

<table>
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<tr>
<th>Category</th>
<th>Unit</th>
<th>Reference</th>
<th>Description</th>
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<tr>
<td>Climate change</td>
<td>kg CO$_2$ eq.</td>
<td>IPCC (2013)</td>
<td>Radiative forcing as Global Warming Potential (GWP100).</td>
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<td>Freshwater eutrophication</td>
<td>kg P eq.</td>
<td>Struijs et al. (2009)</td>
<td>Expression of the degree to which the emitted nutrients reach the freshwater end compartment.</td>
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<td>Land use</td>
<td>points</td>
<td>LANCA model (Bos et al. 2016)</td>
<td>The LANCA model provides five indicators for assessing the impacts due to the use of soil: 1. erosion resistance, 2. mechanical filtration, 3. physicochemical filtration, 4. groundwater regeneration and 5. biotic production</td>
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<tr>
<td>Water resource depletion</td>
<td>m$^3$</td>
<td>Model for water consumption as in Swiss Ecocarcity (Frischknecht et al, 2008)</td>
<td>Water use related to local scarcity of water</td>
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</table>
| Mineral, fossil and renewable resource depletion | kg Sb eq. | Van Oers et al. (2002) | Scarcity of resource in relation to that of antimony. Scarcity is calculated as « reserve base ».
TECHNOLOGY PARAMETERS
Results
Variations are due to region-specific electricity mixes, fossil fuel chain, and climate conditions.
Variations are due to the decarbonisation of the electricity background. In Europe.

## And in 2050?

### Difference in lifecycle GHG emissions between 2020 and 2050 (SSP2), region EUR

![Graph showing differences in lifecycle GHG emissions between 2020 and 2050 for various energy sources and technologies. The graph indicates that emissions decrease significantly in 2050 compared to 2020 across all categories.](image)

### Key Data:
- **PC, without CCS**: 660 MW
- **IGCC, without CCS**: 360 MW
- **SC, without CCS**: average
- **NGCC, without CCS**: trough
- **PC, with CCS**: poly-Si, ground-mounted
- **IGCC, with CCS**: poly-Si, roof-mounted
- **SC, with CCS**: CdTe, ground-mounted
- **NGCC, with CCS**: CdTe, roof-mounted
- **Hard coal**: onshore, concrete foundation
- **Natural gas**: offshore, steel foundation

### Technological Breakdown:
- **Hard coal**
- **Natural gas**
- **Poly-Si, ground-mounted**
- **Poly-Si, roof-mounted**
- **CdTe, ground-mounted**
- **CdTe, roof-mounted**
- **CIGS, ground-mounted**
- **CIGS, roof-mounted**
- **PV**
- **CSP**
- **Wind**
FRESHWATER EUTROPHICATION

Life cycle emissions for each region, g phosphorus/MWh

Mostly phosphate emissions from mining

Variations are due to region-specific electricity mixes, fossil fuel chain, and climate conditions
Life cycle emissions for each region, kg $^{235}\text{U}$ eq./MWh

Variations are due to region-specific electricity mixes, fossil fuel chain, and climate conditions.
**LAND USE**

**Lifecycle land occupation, in points***

*The LANCA model provides five indicators for assessing the impacts due to the use of soil: 1. erosion resistance, 2. mechanical filtration, 3. physicochemical filtration, 4. groundwater regeneration and 5. biotic production – all aggregated as points.

<table>
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<tr>
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</table>
Lifecycle water requirements, in m³/MWh (l/kWh)

Variations are due to region-specific electricity mixes, fossil fuel chain, and climate conditions.
Lifecycle resource requirements, scarcity-weighted, in g Sb eq./kWh

Life cycle mineral and metal requirement, in g Sb eq. per MWh, regional variation, 2020

Variations are due to region-specific electricity mixes, fossil fuel chain, and climate conditions.
Lifecycle material requirements, extracted from ground, in g/MWh

Material requirements, in g per MWh

- Zinc
- Silicon
- Nickel
- Molybdenum
- Manganese
- Copper
- Cobalt
- Chromium
- Aluminium

CSP | Hard coal | Hydro | Natural gas | PV | Wind | Nuclear
---|-----------|-------|------------|----|------|-------
IGCC, with CCS | IGCC, without CCS | PC, with CCS | PC, without CCS | SC, with CCS | SC, without CCS | 360 MW | 660 MW | CdTe, ground-mounted | CdTe, roof-mounted | CIGS, ground-mounted | CIGS, roof-mounted | poly-Si, ground-mounted | poly-Si, roof-mounted | offshore, concrete foundation | offshore, steel foundation | onshore | average
RESOURCES, PRIMARY ENERGY

Primary energy demand over lifecycle, in MJ of energy carrier from ground

Lifecycle cumulative energy demand, in MJ/kWh (primary, non-renewable and renewable)
Primary energy demand over lifecycle, in MJ of fossil energy from ground

Lifecycle cumulative energy demand, in MJ/kWh (primary, fossil)
RESULTS UNECE REGIONS — EUR

Different visualisation

Environmental impacts from electricity production, Europe EU

- Land use: 3.54E+00
- Freshwater eutrophication: 9.40E-01 kg CO2-Eq
- Acidity: 4.61E-04 kg P-Eq
- Respiratory effects: 4.05E-04 kg U235-Eq
- Water dissipation: 3.51E-01 g
- Ionising radiation: 8.59E-04 m3

Non-renewable resources

- Concentrated solar power Tower
- Hard coal PC, with CCS
- Hard coal PC, without CCS
- Hydropower 360 MW
- Natural gas NGCC, with CCS
- Natural gas NGCC, without CCS
- Nuclear power PWR
- Photovoltaics Poly-Si, utility
- Wind Onshore
AGGREGATED SCORES

Endpoint indicators: human health

Lifecycle impacts on human health, excluding climate change, per kWh, in millipoints

- photochemical oxidant formation
- particulate matter formation
- ozone depletion
- ionising radiation
- human toxicity

- CSP
- Hard coal
- Hydro
- Natural gas
- PV
- Wind
- Nuclear
AGGREGATED SCORES

Endpoint indicators: human health

Lifecycle impacts on ecosystems, excluding climate change, per kWh, in micropoints

- urban land occupation
- terrestrial ecotoxicity
- terrestrial acidification
- natural land transformation
- marine ecotoxicity
- freshwater eutrophication
- freshwater ecotoxicity
- agricultural land occupation

CSP | Hard coal | Hydro | Natural gas | PV | Wind | Nuclear

0.7 0.7 | 1.2 | 0.9 | 1.5 | 1.1 | 1.4 | 1.0 | 0.8 0.8 | 0.3 0.2 | 0.5 | 0.5 | 0.1 0.1 | 0.8 | 0.4 | 0.1 0.0 0.0 0.0 0.0
Results per technology
COAL POWER

Lifecycle impacts per kWh (PC 550 MW, 30-year lifetime)

- Minerals and metals: 2.84e-07 kg Sb-Eq
- Water: 1.11e-01 m³ water-
- Land use: 2.39e+00 points
- Ionising radiation: 3.94e-03 kg U235-Eq
- Freshwater eutrophication: 4.85e-04 kg P-Eq
- Climate change: 9.62e-01 kg CO2-Eq
LIFE CYCLE IMPACTS PER kWh (PC 550 MW, 30-year lifetime)

- Minerals and metals: 4.96e-07 kg Sb-Eq
- Water: 2.01e-01 m3 water-
- Land use: 3.40e+00 points
- Ionising radiation: 6.46e-03 kg U235-Eq
- Freshwater eutrophication: 6.86e-04 kg P-Eq
- Climate change: 2.83e-01 kg CO2-Eq
Lifecycle impacts per kWh (NGCC 555 MW, 30-year lifetime)
NATURAL GAS WITH CCS

Lifecycle impacts per kWh (NGCC 555 MW, 30-year lifetime)
HYDROPOWER

Lifecycle impacts per kWh (360 MW, 80-year lifetime)

- Minerals and metals
- Water
- Land use
- Ionising radiation
- Freshwater eutrophication
- Climate change

- 4.08e-08 kg Sb-Eq
- 1.12e-03 m3 water-
- 1.42e-01 points
- 5.65e-04 kg U235-Eq
- 8.96e-07 kg P-Eq
- 7.21e-03 kg CO2-Eq
PHOTOVOLTAICS

Lifecycle impacts per kWh (poly-Si, ground, 25-year lifetime)

- Minerals and metals
- Water
- Land use
- Ionising radiation
- Freshwater eutrophication
- Climate change

- Electricity production, photovoltaic, polycrystalline silicon, ground-mounted, THEMIS' (kilowatt hour, USA, None)

- Minerals and metals: 3.67e-06 kg Sb-Eq
- Water: 1.83e-02 m³ water-
- Land use: 1.49e+00 points
- Ionising radiation: 5.77e-03 kg U235-Eq
- Freshwater eutrophication: 2.60e-05 kg P-Eq
- Climate change: 3.33e-02 kg CO2-eq

Legend:
- Poly Ground System (unit, EUR, None)
- 3.63 m² module (unit, EUR, None)
- High-grade silicon, at plant (kilogram, EUR, None)
- PER silicon, solar grade, at plant (kilogram, EUR, None)
- 'silicon, solar grade, modified Siemens process, at plant' (kilogram, EUR, None)
- 'Silicon cell, multi-crystal, pieces, produced in Factory' (unit, EUR, None)
- Polycrystalline silicon module230w (unit, EUR, None)
- Inverters (unit, EUR, None)
- Construction (unit, EUR, None)
- 'Operation and Maintenance' (unit, EUR, None)
- 'External cabling, grid connection' (kilometer, EUR, None)
- 'Decommissioning' (unit, EUR, None)
WIND POWER
Lifecycle impacts per kWh (onshore, 2.5 MW, 20-year)
Lifecycle impacts per kWh (1000 MW PWR, 60 year lifetime)

- Minerals and metals: 1.10e-07 kg Sb eq.
- Water: 1.06e-02 m³
- Land use: 5.20e-02 points
- Ionising radiation: 5.80e-01 kg 235U eq.
- Freshwater eutrophication: 5.39e-06 kg P eq.
- Climate change: 4.58e-03 kg CO₂ eq.
Lifecycle impacts per kWh

Analysis has not been done but data is available for modular versions of light-water reactors.

Existing studies indicate similar ranges for LWR SMRs.

Results presentation – discussion
Simplify contribution graphs

Use percentages
Reduce the amount of text to the necessary
Group categories together?
Adapt units ("3.6e-07 kg P" = "0.36 mg P")
-> only show UNECE regions?

Finalize report

Commenting results
Discussion on hotspots/blindspots from LCA
Outlook and opportunities for further work