

# LCA OF ELECTRICITY GENERATION TECHNOLOGIES

UNECE modelling activities – Carbon neutrality project

01.07.2021

# CONTEXT OF LIFE CYCLE ASSESSMENT TASK

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

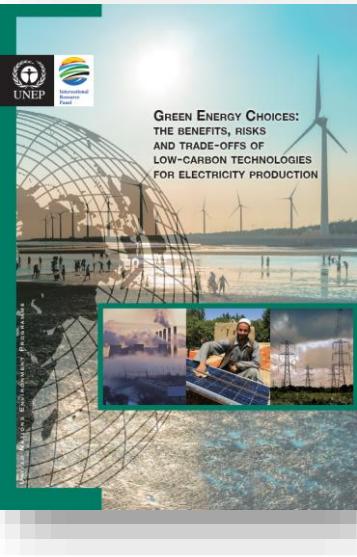
Concentrating solar power

Photovoltaic power

Geothermal power

Impact assessment over 2010-2050 period

Two IEA scenarios (Baseline, Blue Map) and 9 world regions



# CONTEXT OF LCA TASK

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

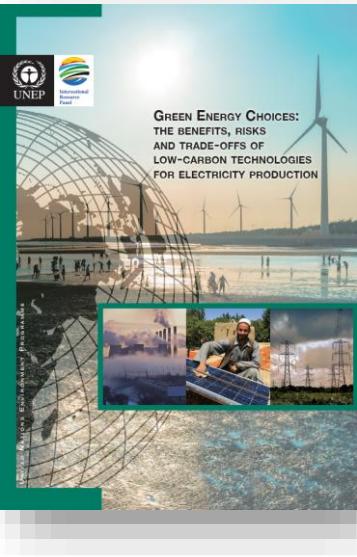
No consistent end-of-life treatment consideration across technologies

Energy scenarios outdated: use REMIND?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

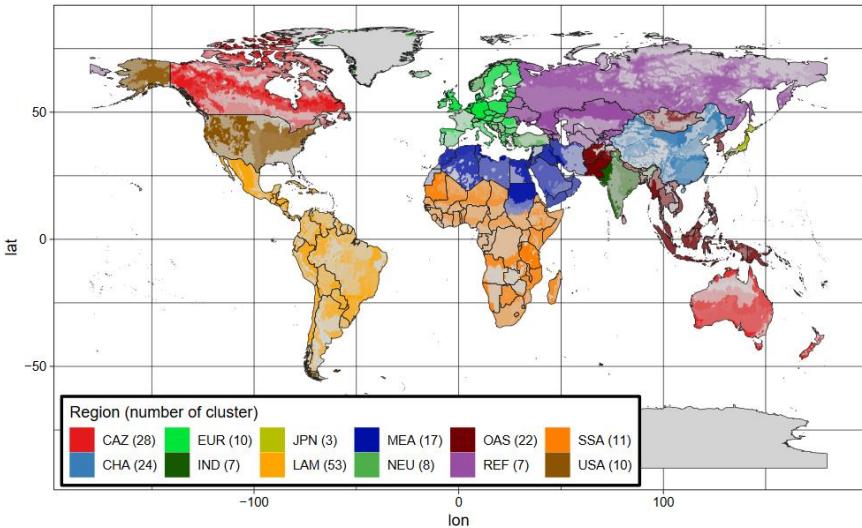
## Why regionalizing?

### 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

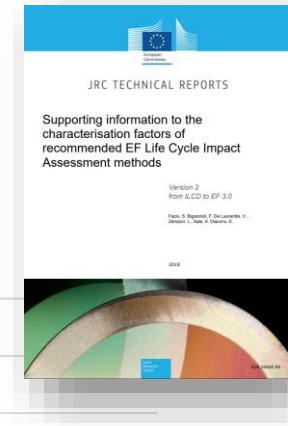
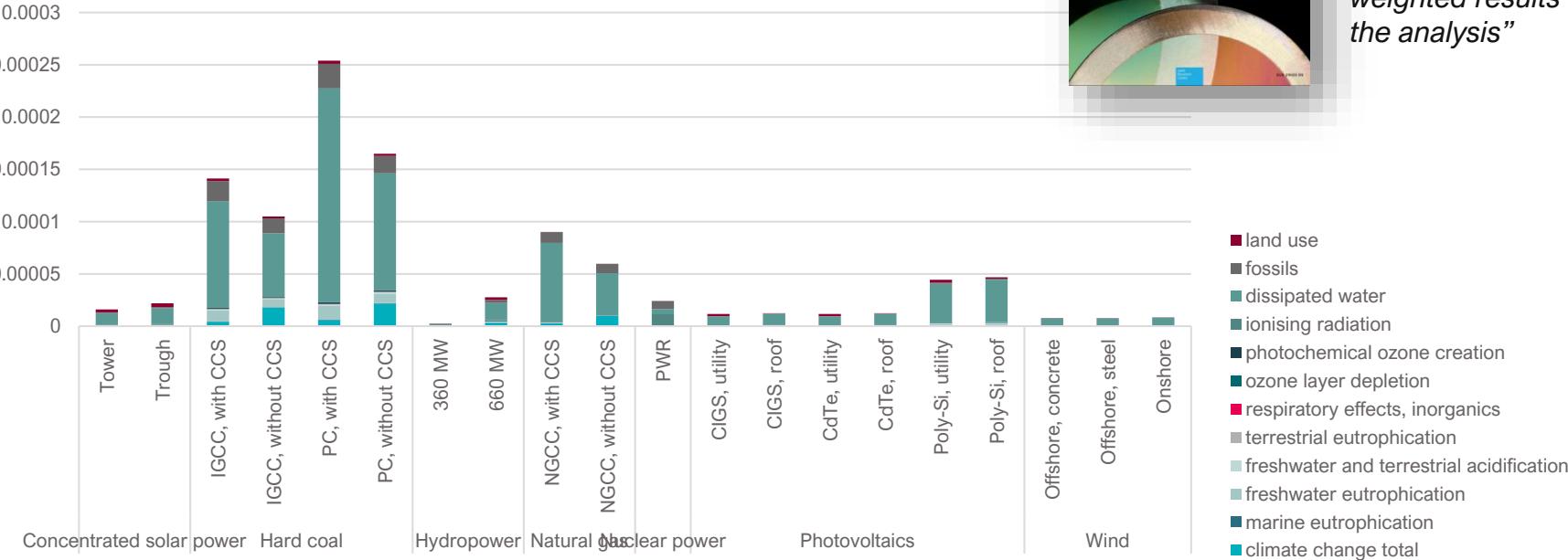
Solar irradiation  
Wind regimes



REMIND regions	Code
Canada, Australia & New Zealand	CAZ
China	CHA
European Union	EUR
India	IND
Japan	JPN
Latin America	LAM
Middle East and North Africa	MEA
Non-EU member states	NEU
Other Asia	OAS
Reforming countries	REF
Sub Saharan Africa	SSA
United States	USA

# CHOOSING INDICATORS

## 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"*

# CHOOSING INDICATORS

## List of retained indicators, following EC recommendations

Category	Unit	Reference	Description
Climate change	kg CO <sub>2</sub> eq.	IPCC (2013)	Radiative forcing as Global Warming Potential (GWP100).
Freshwater eutrophication	kg P eq.	Struijs et al. (2009)	Expression of the degree to which the emitted nutrients reach the freshwater end compartment.
Ionising radiation (HH)	kBq <sup>235</sup> U eq	Frischknecht et al (2000)	Human exposure efficiency relative to U235.
Land use	points	LANCA model (Bos et al. 2016)	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
Water resource depletion	m <sup>3</sup>	Model for water consumption as in Swiss Ecoscarcity (Frischknecht et al, 2008)	Water use related to local scarcity of water
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 ».

+ cumulative energy demand  
+ endpoint score  
as information

# TECHNOLOGY PARAMETERS

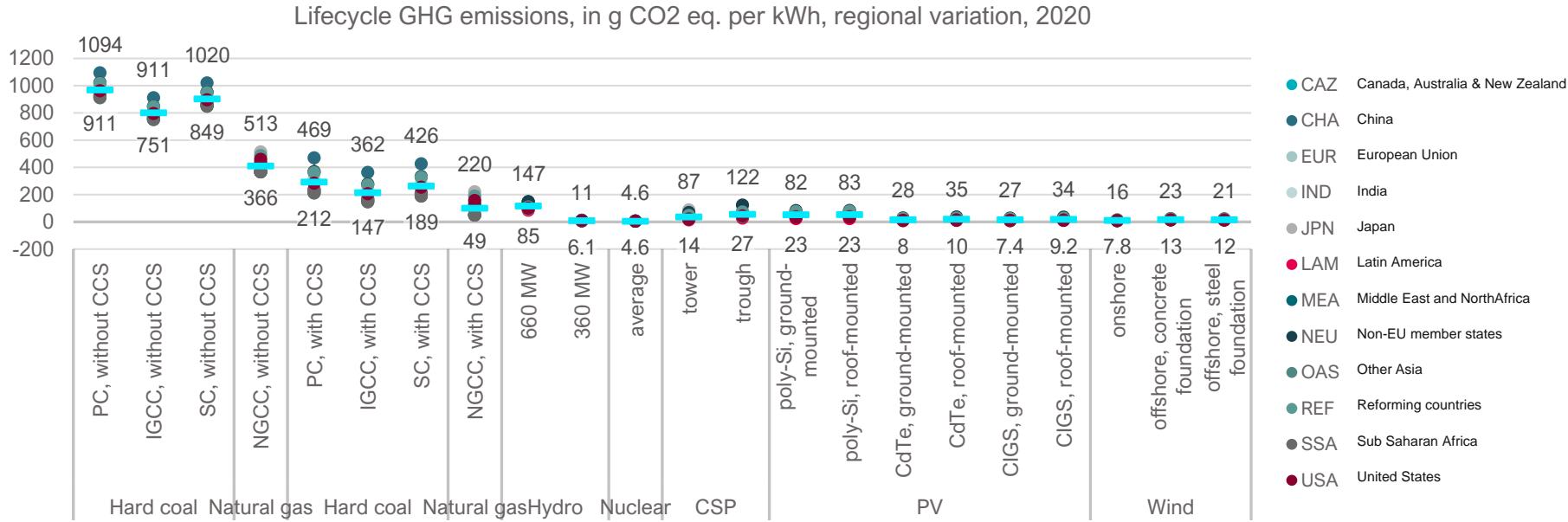
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## Results

# CLIMATE CHANGE

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

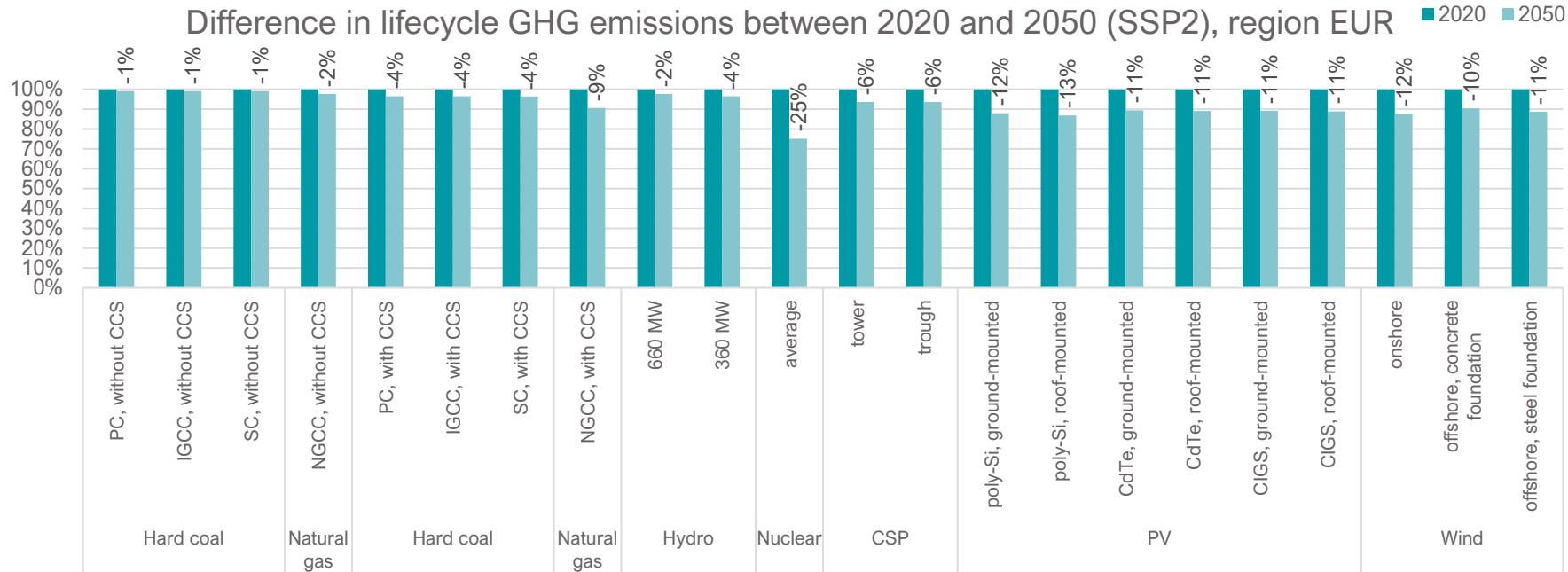
## Life cycle emissions for each region, g CO<sub>2</sub> eq./kWh



# CLIMATE CHANGE

And in 2050?

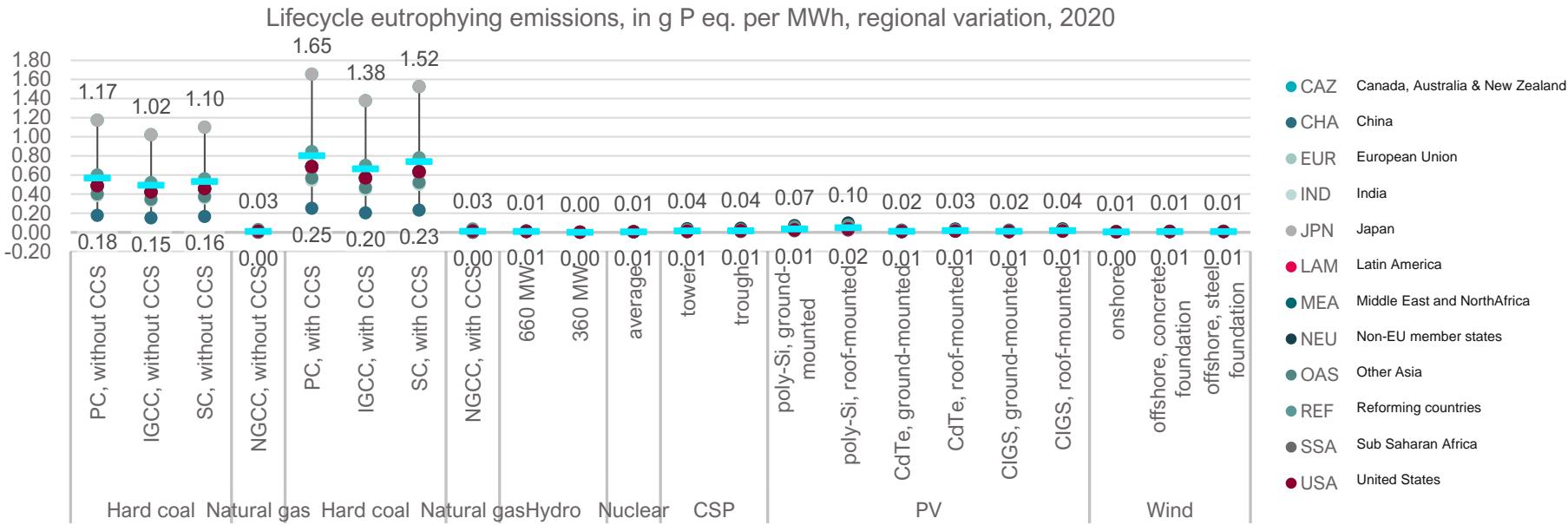
Variations are due to the decarbonisation of the electricity background.  
In Europe



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

# FRESHWATER EUTROPHICATION

## Life cycle emissions for each region, g phosphorus/MWh

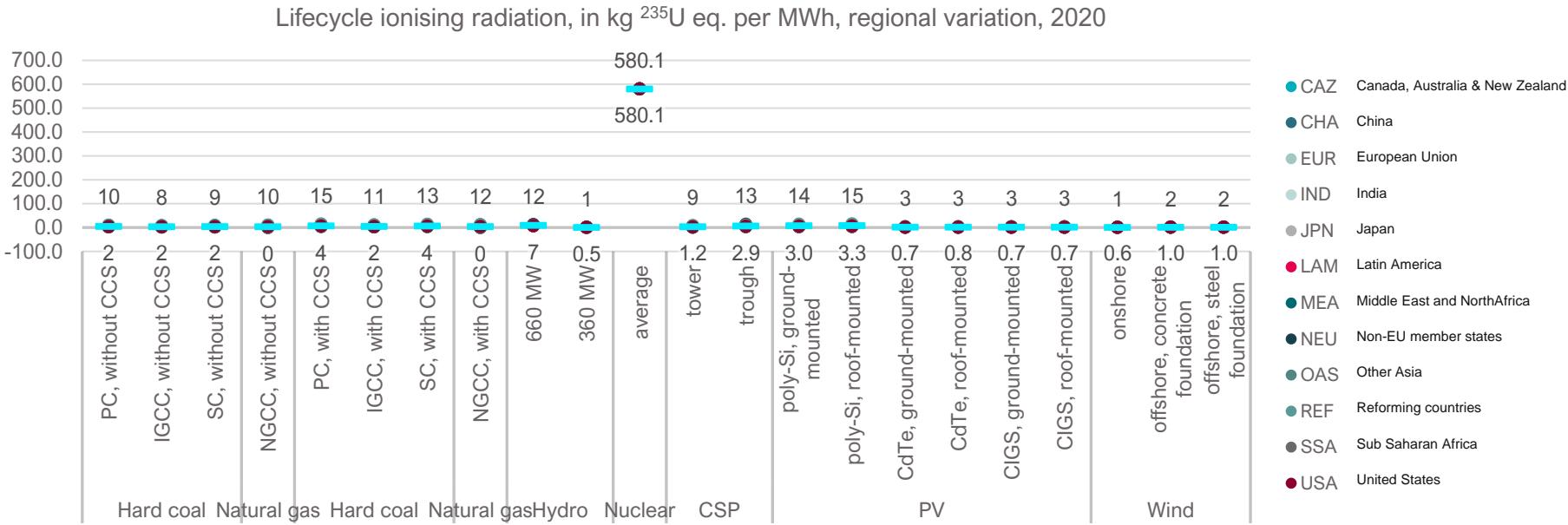


Mostly phosphate emissions from mining

# IONISING RADIATION

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



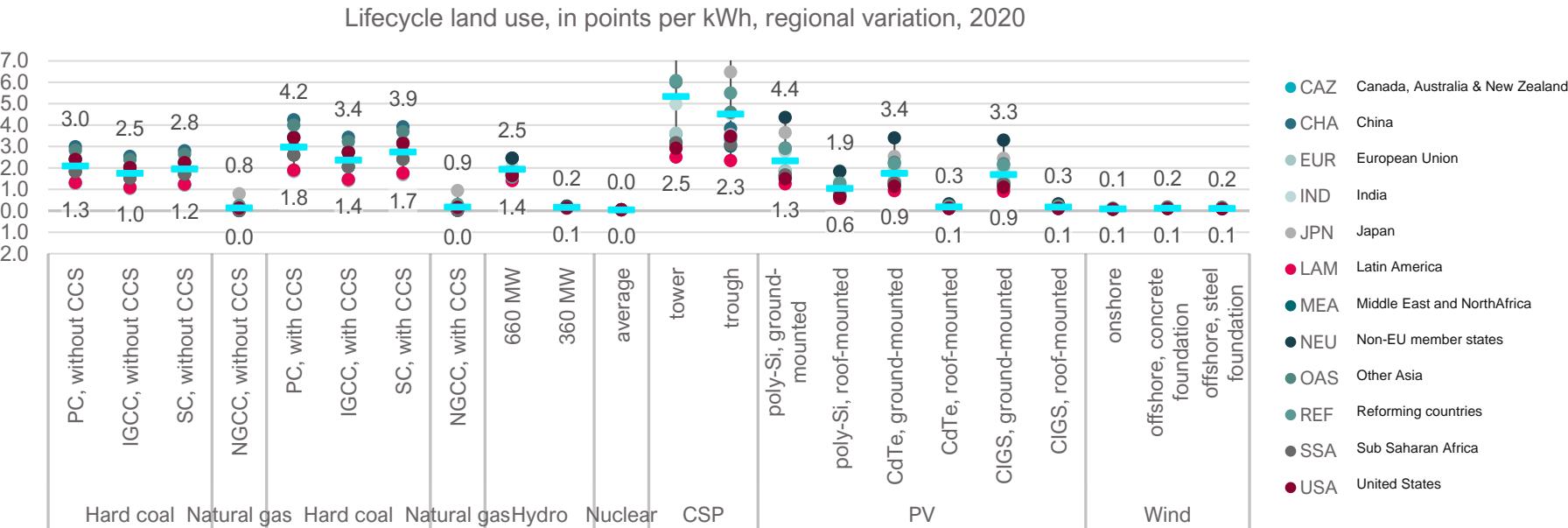
# LAND USE

## 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

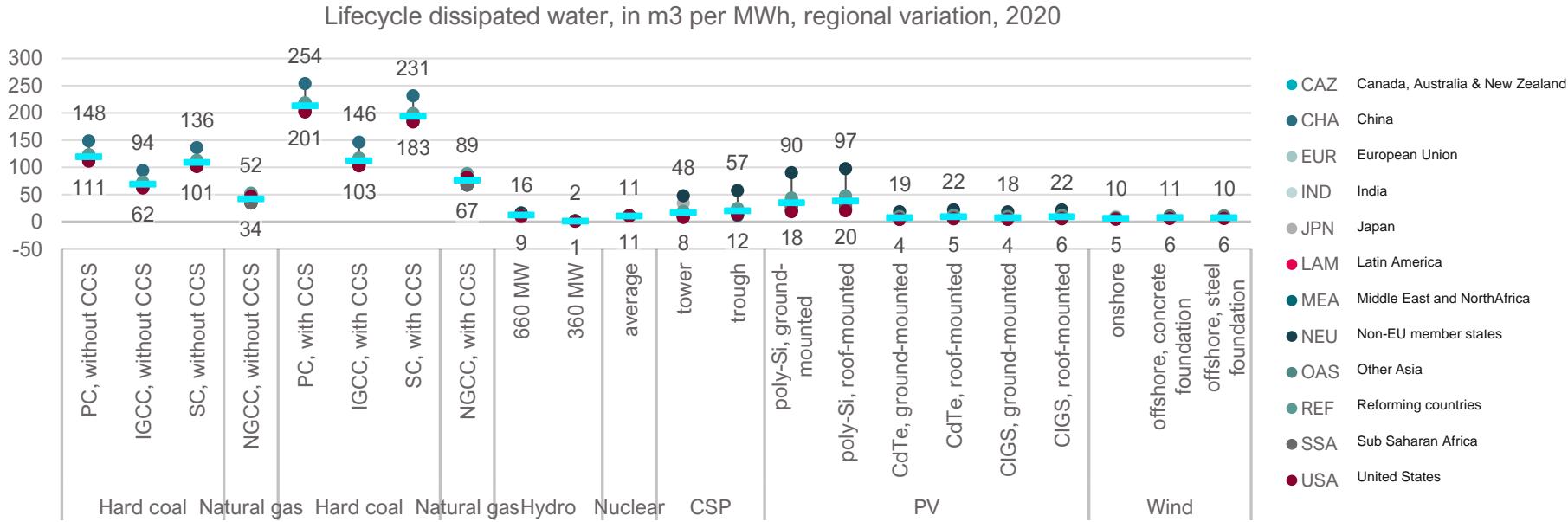
– all aggregated as points.



# DISSIPATED WATER

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

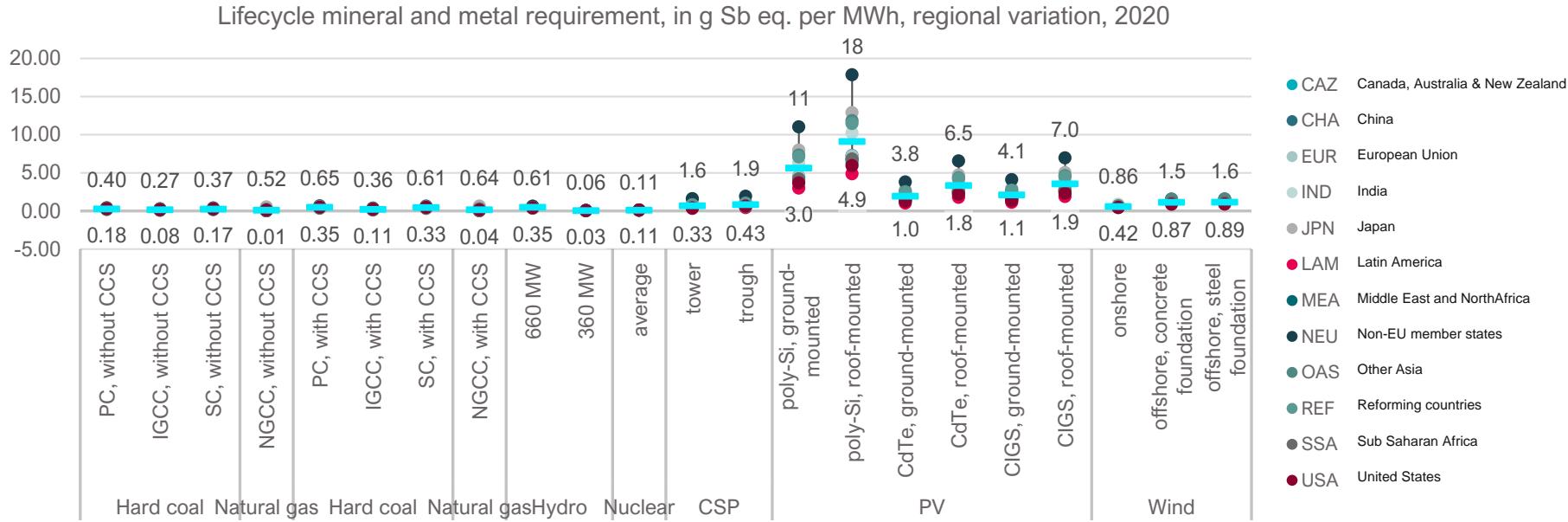
## Lifecycle water requirements, in m<sup>3</sup>/MWh (l/kWh)



# RESOURCES, MATERIAL

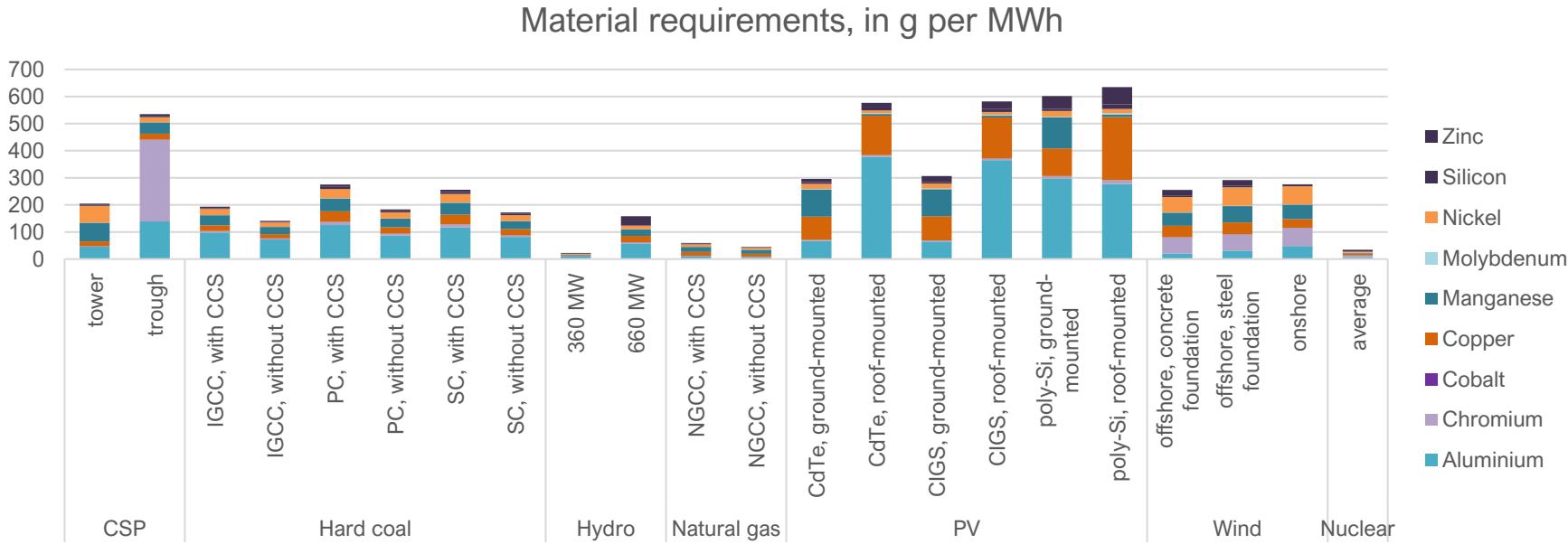
Variations are due to region-specific electricity mixes, fossil fuel chain, and climate conditions

## Lifecycle resource requirements, scarcity-weighted, in g Sb eq./kWh



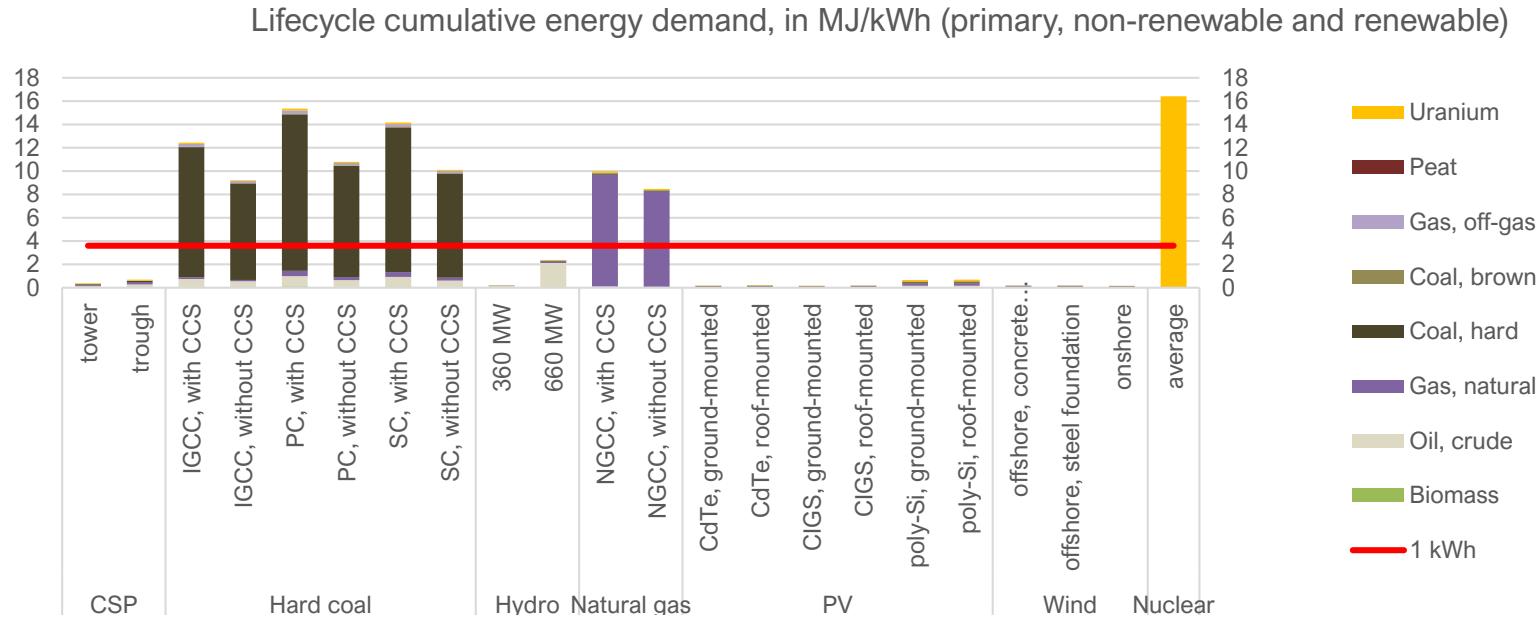
# RESOURCES, MATERIAL

## Lifecycle material requirements, extracted from ground, in g/MWh



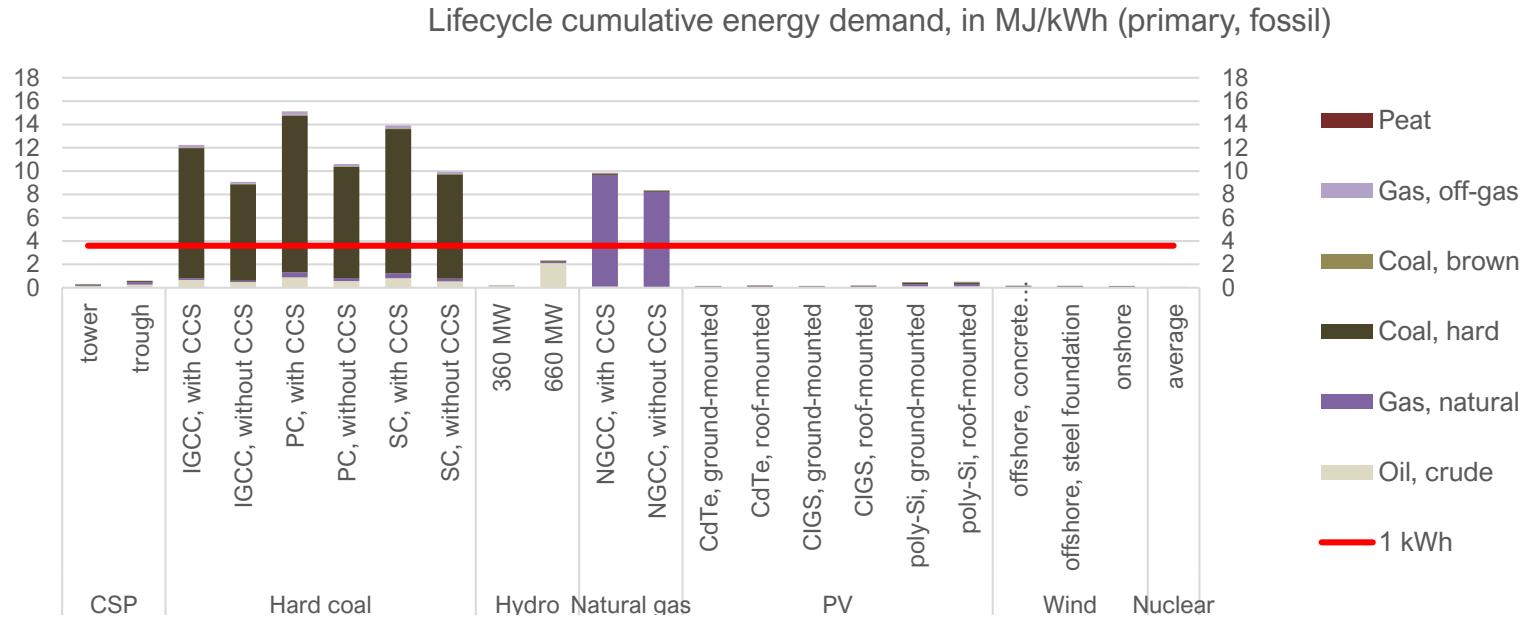
# RESOURCES, PRIMARY ENERGY

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



# RESOURCES, PRIMARY ENERGY

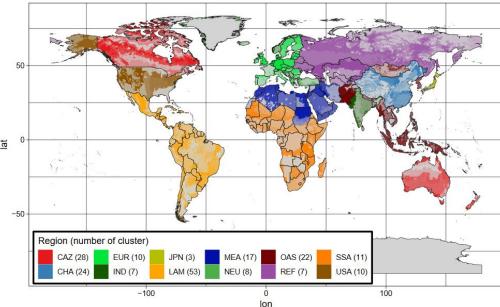
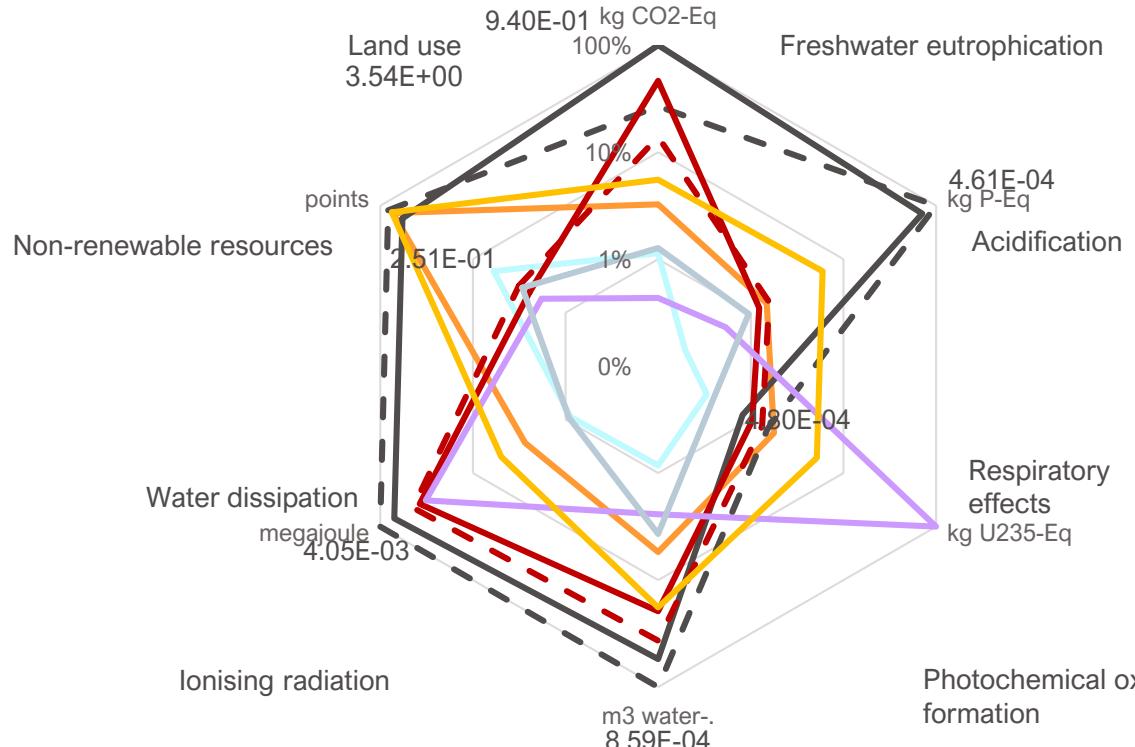
## Primary energy demand over lifecycle, in MJ of fossil energy from ground



# RESULTS UNECE REGIONS – EUR

## Different visualisation

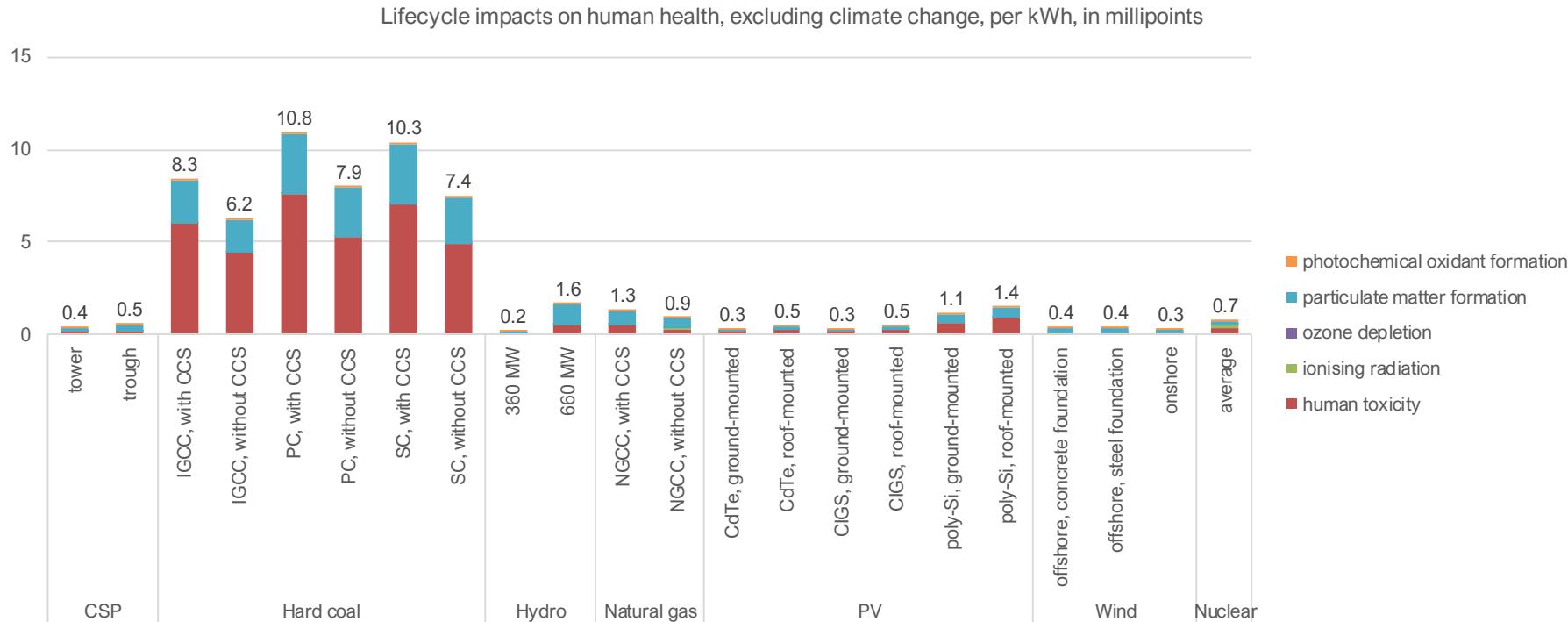
Environmental impacts from electricity production, Europe EU



- 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

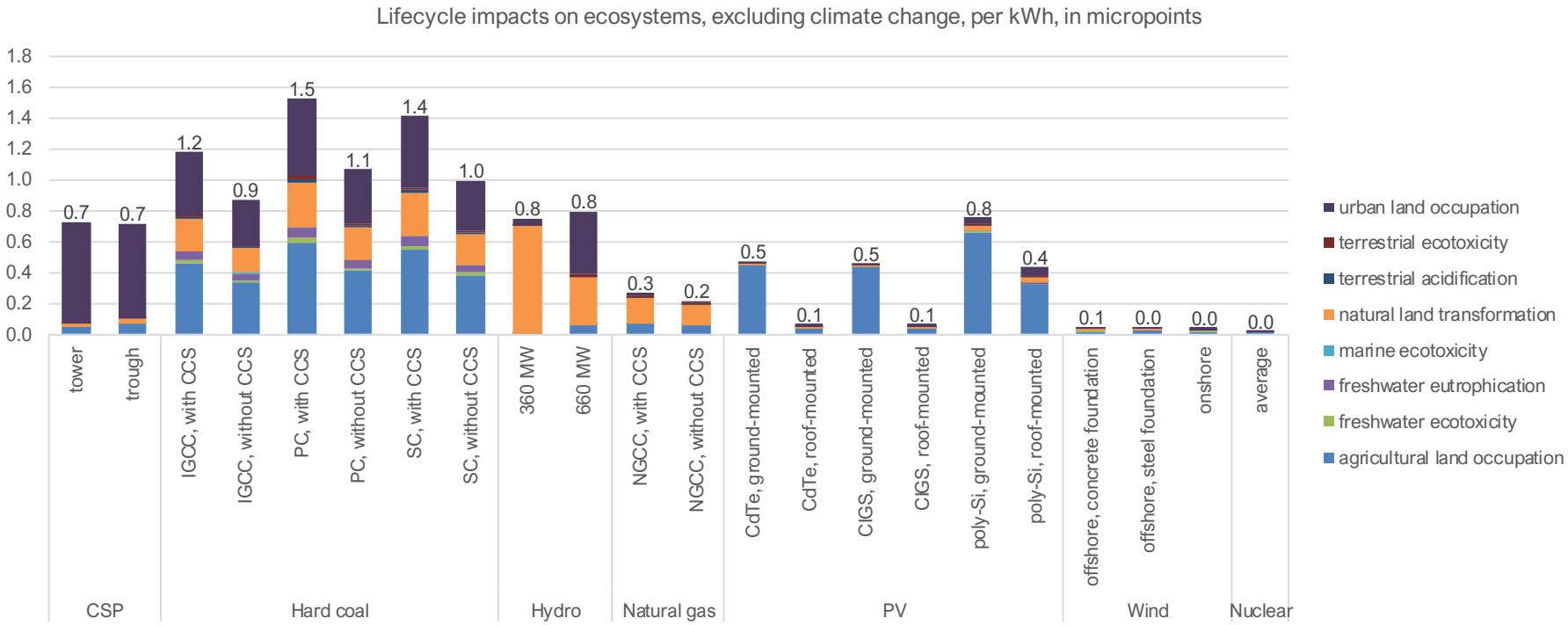
# AGGREGATED SCORES

## Endpoint indicators: human health



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## Endpoint indicators: human health



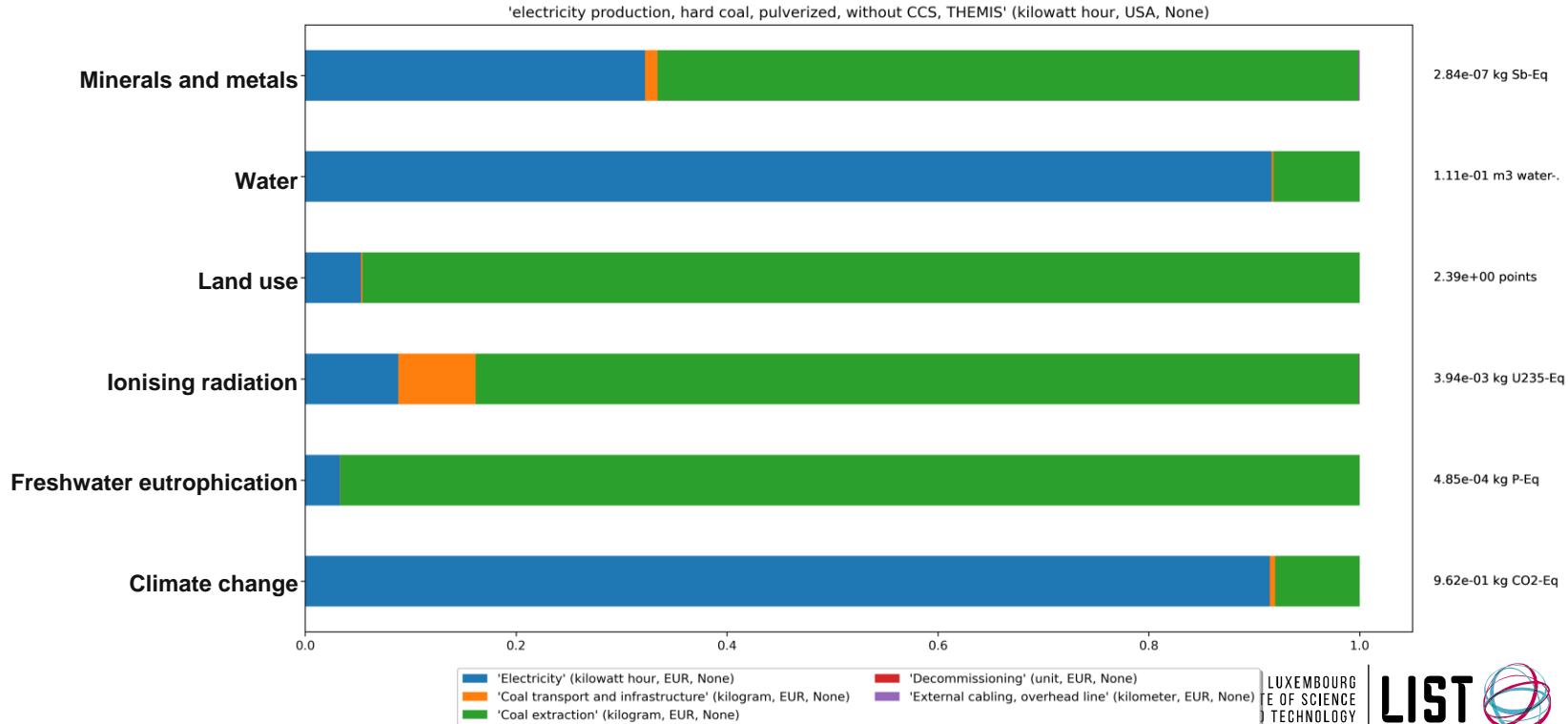
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## Results per technology

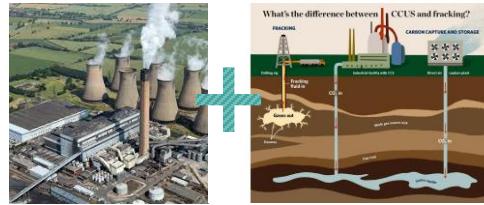
# COAL POWER



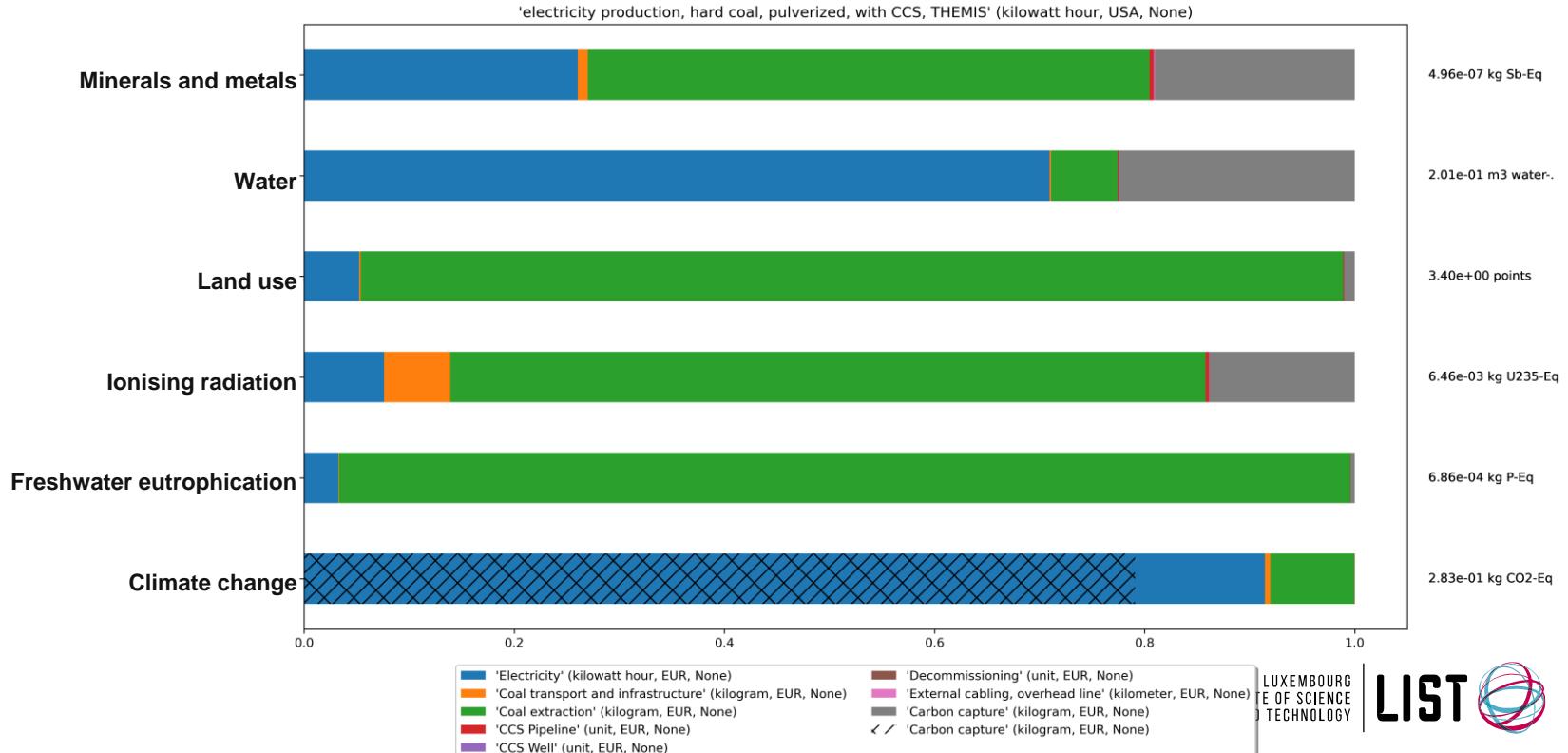
## Lifecycle impacts per kWh (PC 550 MW, 30-year lifetime)



# COAL POWER WITH CCS



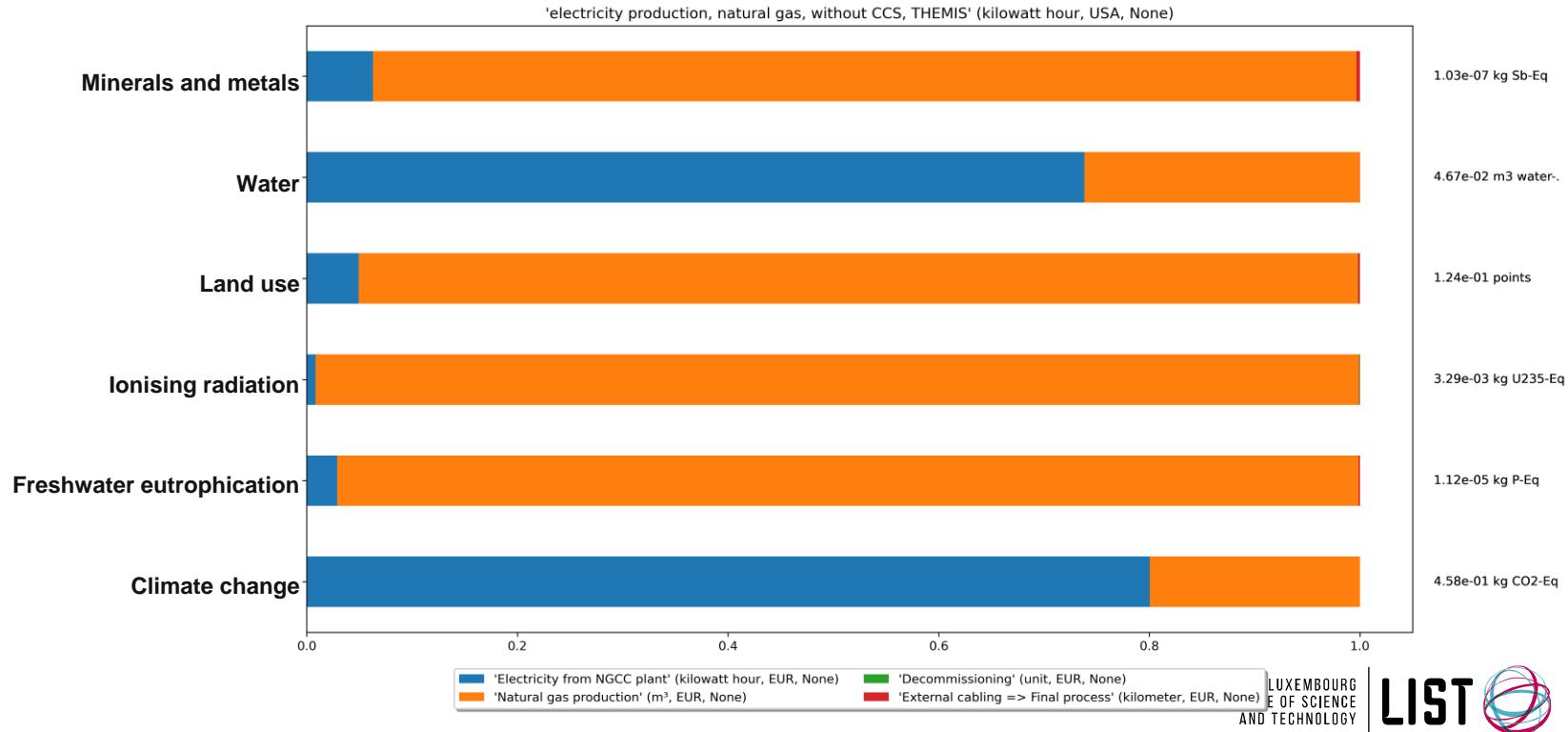
## Lifecycle impacts per kWh (PC 550 MW, 30-year lifetime)



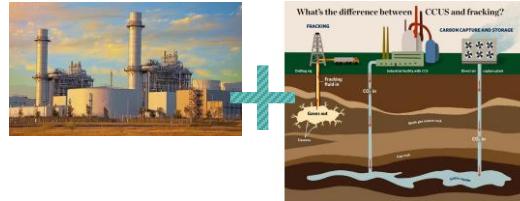
# NATURAL GAS



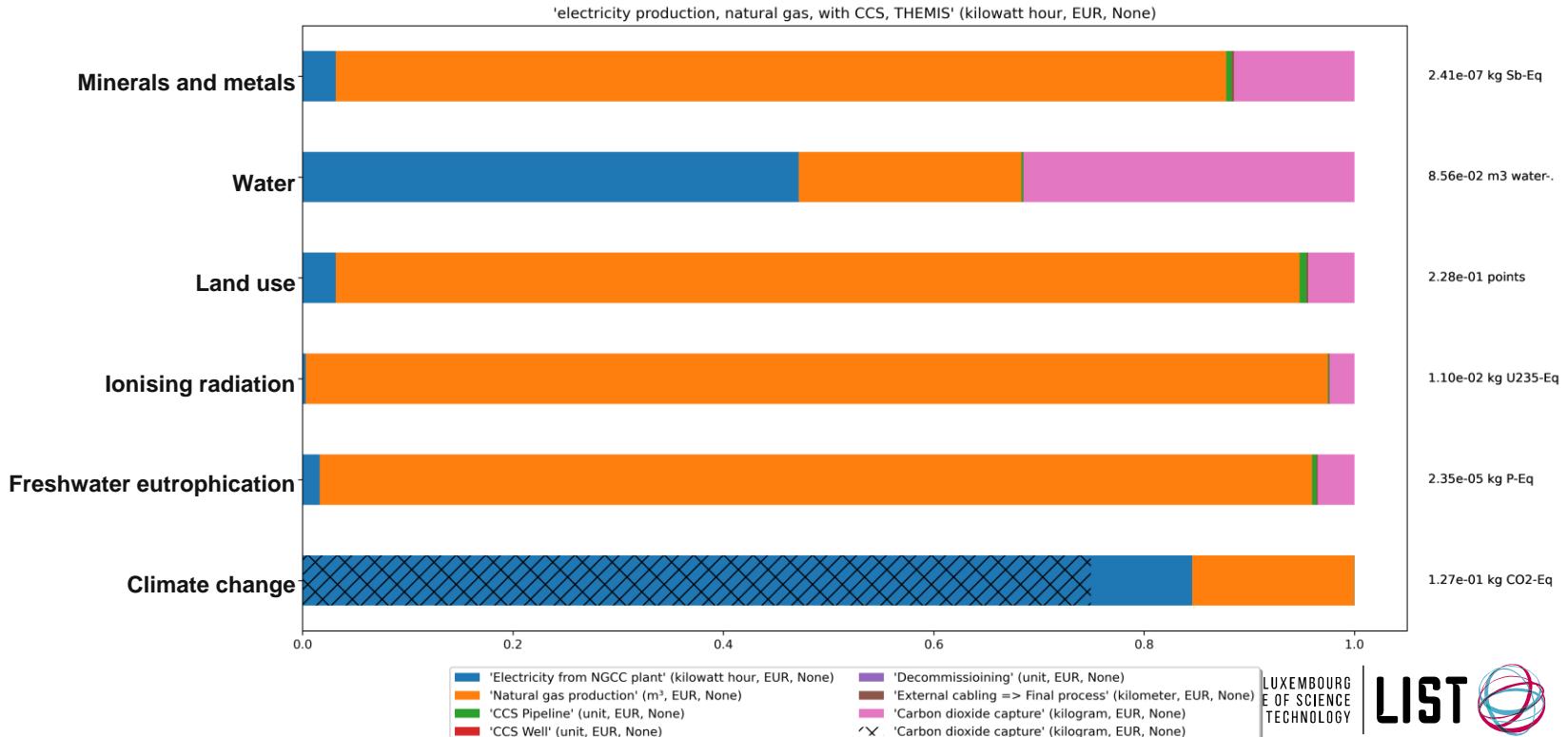
## Lifecycle impacts per kWh (NGCC 555 MW, 30-year lifetime)



# NATURAL GAS WITH CCS



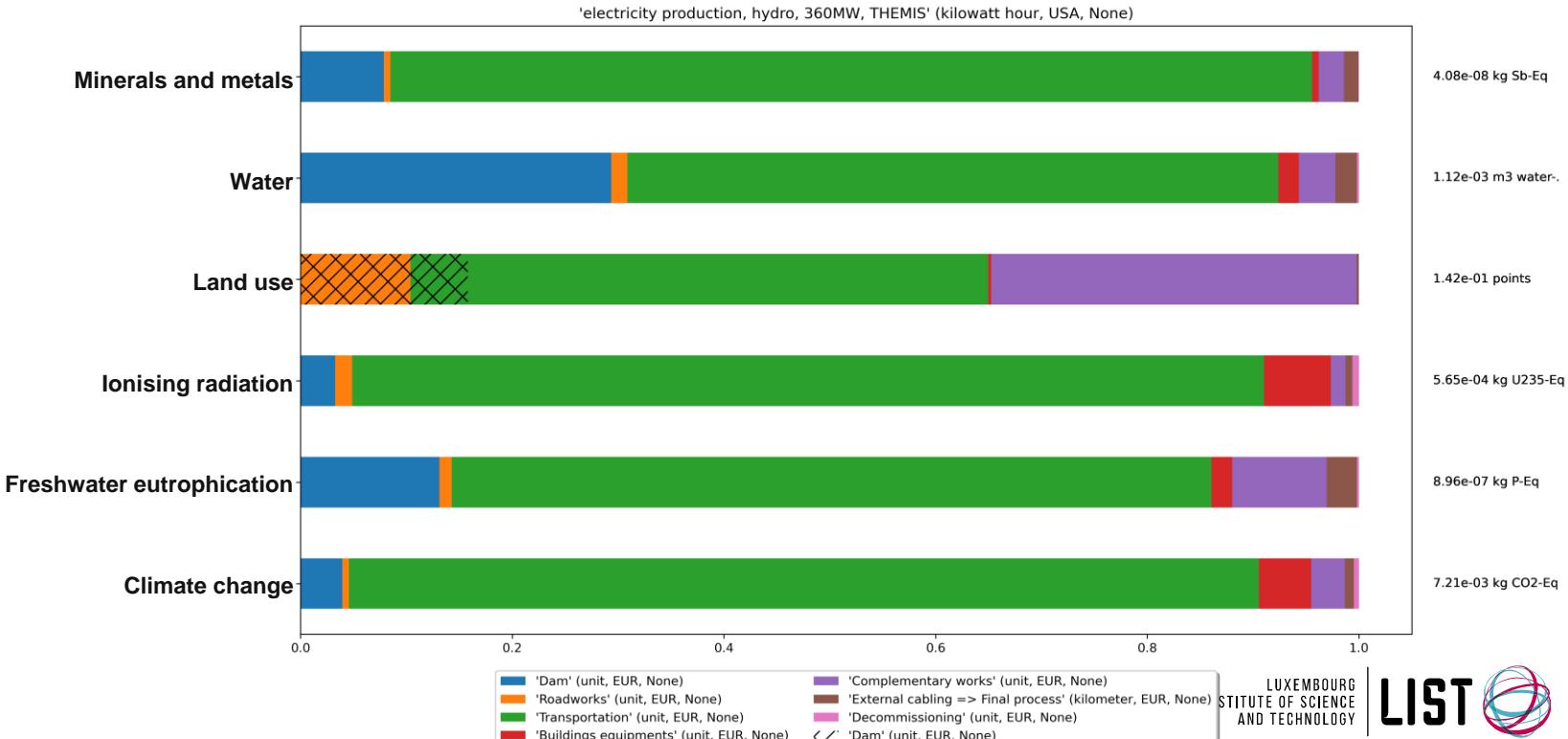
## Lifecycle impacts per kWh (NGCC 555 MW, 30-year lifetime)



# HYDROPOWER



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

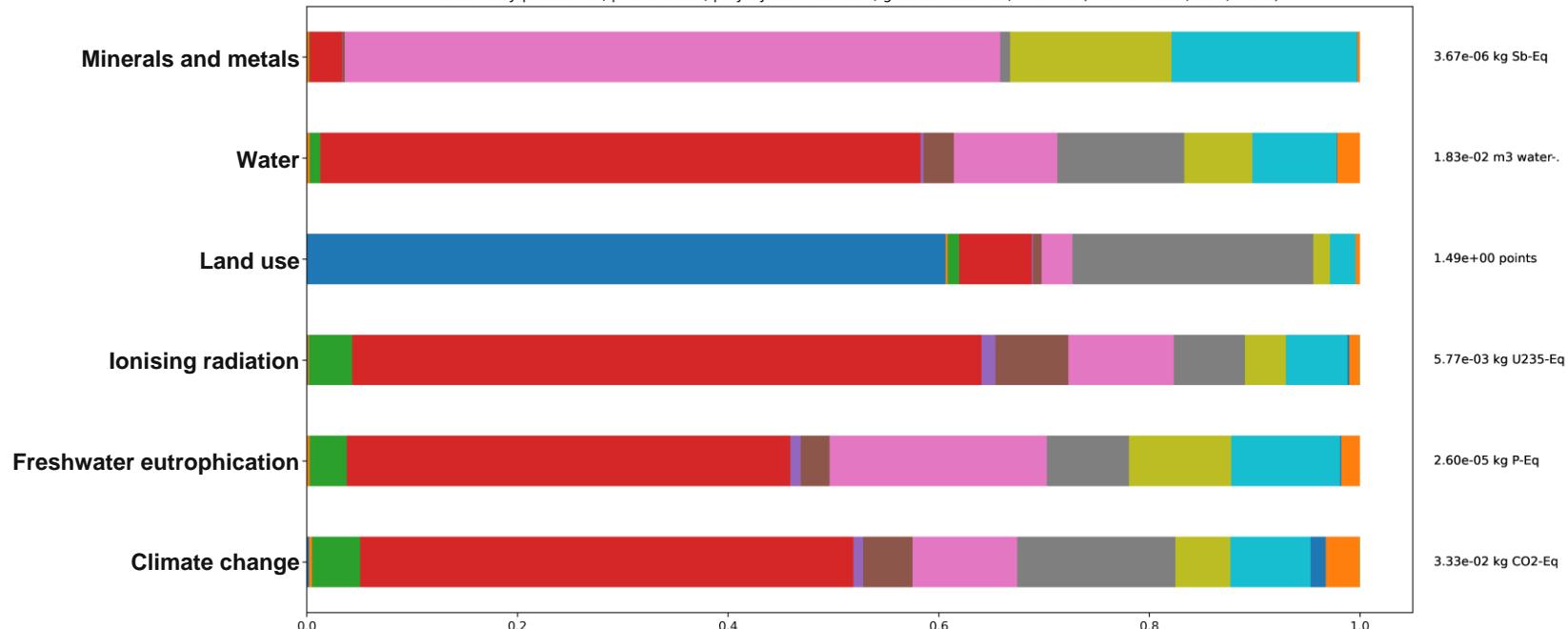


# PHOTOVOLTAICS



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

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



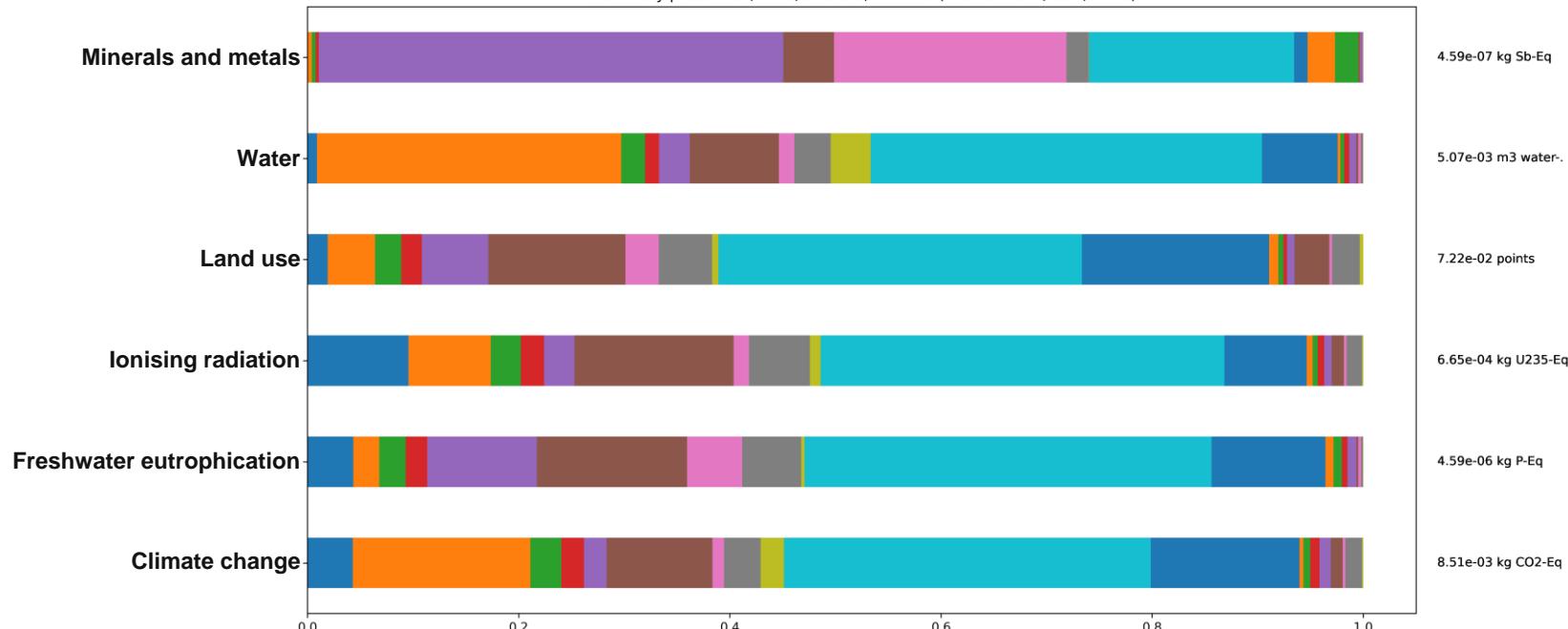
'Poly Ground System' (unit, EUR, None)	'Polycrystal silicon module230w' (unit, EUR, None)
'1.63 m2 module' (unit, EUR, None)	'Inverters' (unit, EUR, None)
'MG-silicon,at plant' (kilogram, EUR, None)	'Construction' (unit, EUR, None)
'RE:silicon, solar grade-pc, at plant' (kilogram, EUR, None)	'Operation and Maintenance' (unit, EUR, None)
'silicon,solar grade,modified Siemens process, at plant' (kilogram, EUR, None)	'External cabling, grid connection' (kilometer, EUR, None)
'multi-silicon wafer 125/125.0.2' (unit, EUR, None)	'Decommissioning' (unit, EUR, None)
'silicon cell,multi-crystal, pieces, produced in Factory' (unit, EUR, None)	

# WIND POWER

## Lifecycle impacts per kWh (onshore, 2.5 MW, 20-year)



'electricity production, wind, onshore, THEMIS' (kilowatt hour, USA, None)



'Wind turbine, misc. assembly activities' (unit, EUR, None)	'Foundation, gravity-based concrete, onshore' (kilogram, EUR, None)
'Rotor blades' (kilogram, EUR, None)	'Transformer station (high-voltage), onshore' (kilogram, EUR, None)
'Rotor hub, incl. nose cone' (kilogram, EUR, None)	'Internal cabling, underground onshore' (kilogram, EUR, None)
'Bed frame/plate' (kilogram, EUR, None)	'External cabling, underground onshore' (kilometer, EUR, None)
'Generator (conventional)' (kilogram, EUR, None)	'External cabling, overhead line' (kilometer, EUR, None)
'Gearbox' (kilogram, EUR, None)	'Installation, onshore WF' (unit, EUR, None)
'Main shaft' (kilogram, EUR, None)	'Replacement of parts, category small parts (SP), onshore' (n, EUR, None)
'Cover' (kilogram, EUR, None)	'Maintenance (excl. spare parts), onshore WF' (unit, EUR, None)
'Tower, tubular steel, onshore' (kilogram, EUR, None)	'Decommissioning, onshore' (unit, EUR, None)

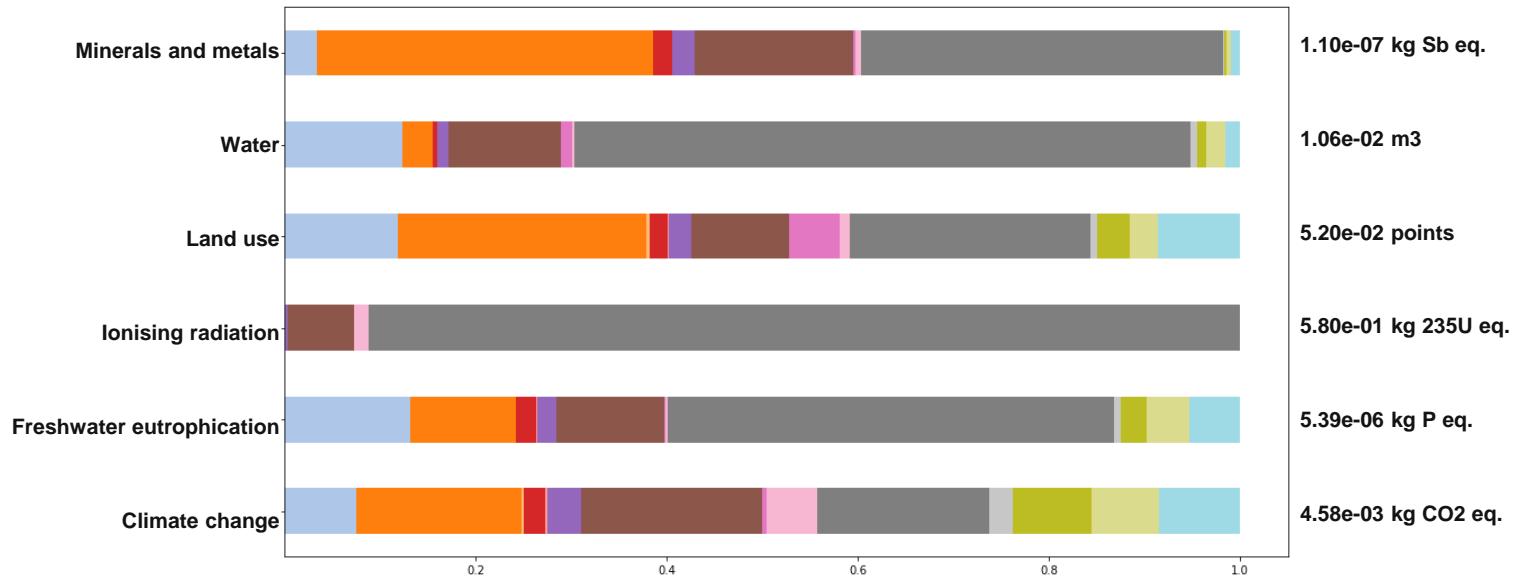
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LOGY

LIST

# NUCLEAR POWER



## Lifecycle impacts per kWh (1000 MW PWR, 60 year lifetime)



(electricity production, nuclear, PWR, THEMIS, unep_irp112001)	(Market for uranium hexafluoride, WNA, unep_irp112013)
(Fuel elements, WNA, unep_irp112002)	(Market for uranium, in yellowcake, WNA, unep_irp112014)
(Chemicals, use phase, unep_irp112003)	(Uranium mine operation, open cast, WNA, unep_irp12015)
(Construction elements, unep_irp112004)	(Uranium mine operation, underground, WNA, unep_irp112016)
(Transportation, unep_irp112005)	(Uranium mine operation, in-situ leaching, WNA, unep_irp112017)
(Infrastructure elements and overhead costs, unep_irp112006)	(Electricity, high voltage, uranium conversion mix, unep_irp112018)
(Operating expenses, unep_irp112007)	(Electricity, high voltage, uranium enrichment mix, unep_irp112019)
(Decommissioning costs, unep_irp112008)	(Electricity, medium voltage, uranium milling mix, unep_irp112020)
(External cabling, overhead line, unep_irp112009)	(Interim storage of spent fuel, WNA, unep_irp112021)
(Market for nuclear fuel element, for PWR, WNA, unep_irp112010)	(Encapsulation, WNA, unep_irp112022)
(Market for uranium, WNA, per separative work unit, unep_irp112011)	(Deep waste repository, WNA, unep_irp112023)
(Uranium production, centrifuge, WNA, unep_irp112012)	

# NUCLEAR POWER, SMR?

## Lifecycle impacts per kWh

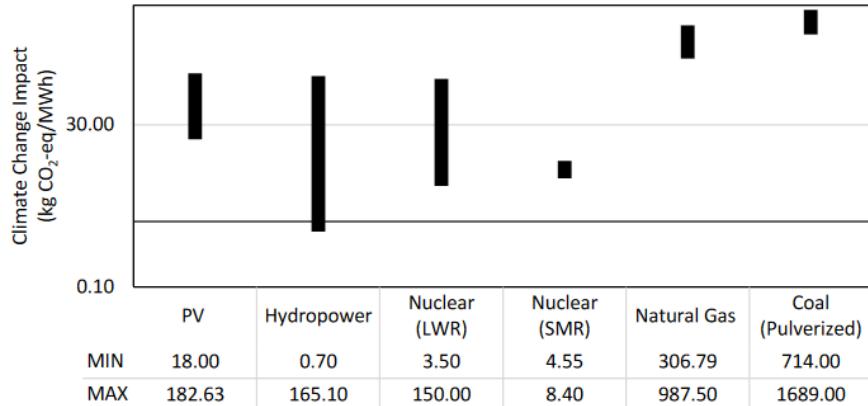


Figure 4.4. Bar graph marking the maximum and minimum LCA climate change impacts of various electricity generators (kg CO<sub>2</sub>-eq/MWh). The nuclear SMR minimum is from this study and the maximum is from Carless et al.<sup>2</sup> All other maximum and minimum values are from OpenEI.<sup>82</sup>

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

Existing studies indicate similar ranges for LWR SMRs

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## Results presentation – discussion

# NEXT STEPS

## Simplify contribution graphs

Use percentages

Reduce the amount of text to the necessary

Group categories together?

Adapt units ("3.6e-07 kg P" = ".36 mg P")

-> only show UNECE regions?

## Finalize report

Commenting results

Discussion on hotspots/blindspots from LCA

Outlook and opportunities for further work