

An aerial photograph of a rugged, rocky coastline at dusk or dawn. The sea is a deep blue, and the sky is a soft purple. Several vibrant, multi-colored lines (red, orange, yellow, green, blue, purple) flow across the landscape, starting from the foreground and moving towards the sea, suggesting energy flows or data paths. The text is overlaid on this scene.

Life cycle assessment of different energy technologies

Environmental Analysis & Ecology

Matteo Frongillo, Anastasia Linnik, Yannik Neukom

Photovoltaic Park

Paper 1:

Estimating the environmental footprint of a grid-connected 20 MWp photovoltaic system

Paper 2:

Life Cycle Assessment of a ground-mounted 1778 kWp photovoltaic plant and comparison with a traditional energy production system

Photovoltaic Park

Data	Paper 1	Paper 2
Geographical reference	Felsőzsolca, Hungary	Marsciano, Italy
Year of publishing	2020	2012
Goal	Assess PV impacts and compare simplified vs. Detailed LCA	Assess PV impacts and compare with conventional energy
Purpose	Early planning and eco-design	Comparative publication study
Audience	Planners, designers	Researchers, engineers, energy stakeholders
PV plant	20 MWp, grid-connected, 25 years	1778 kWp, ground-mounted, grid-connected, 25 years
Primary data	Plant commissioner data	TerniEnergia and on-site data
Secondary data	Ecoinvent v3.5 (2018)	Literature, SimaPro databases
Function	AC electricity to grid	PV electricity
Functional unit	1 kWh AC electricity generator	1 kWp and 1 kWh electricity generated

Photovoltaic Park

Result	Paper 1	Paper 2
Method	PEF methodology (Product Environmental Footprint)	Eco-indicator 99
Total score	3.76 E 5 PEF pt // 4.13 E 5 PEF pt	177 Pt, assembly phase
Life-cycle score	7.5 E -4 PEF pt/kWh (550 GWh lifetime output)	7.34 to 7.79 mPt/kWh (end-of-life scenario)
GWP	6.02 gCO ₂ -eq/kWh // 6.57 gCO ₂ -eq/kWh	88.743 gCO₂-eq/kWh
Main contributor	PV modules and steel structure	PV modules

Nuclear Power Plant

Paper 1:

Title: Life Cycle Assessment (LCA) of Nuclear Power in Switzerland

Year: 2018

Paper 2:

Title: Parametric Life Cycle Assessment of Nuclear Power for Simplified Models

Year: 2023

Summary: Nuclear Power in Switzerland

- **Purpose:** Update life-cycle inventory data for: Kernkraftwerk Gösgen (KKG, PWR) and Kernkraftwerk Leibstadt (KKL, BWR).
- **Methodology:** Primary data from both plants (2014–2017), secondary data from SimaPro and ecoinvent.
- **System boundary:** Uranium mining, milling, conversion, enrichment, fuel fabrication, plant construction, operation, decommissioning, and radioactive waste storage. Nuclear fuel reprocessing excluded.
- **Key findings:** Cradle-to-grave lifecycle per 1 kWh of electricity generated.
 - KKG: 5.6 g CO₂-eq/kWh
 - KKL: 9.4 g CO₂-eq/kWh
- **Main emissions source:** Upstream nuclear fuel processes:
 - 58% of KKG emissions
 - 72% of KKL emissions
- **Publication:** Published by Paul Scherrer Institut (PSI) and funded by Swissnuclear

Summary: Parametric LCA

- **Purpose:** Parametric LCA model for an average of a 1 GWe pressurized water reactor from 2020.
- **Methodology:** Primary data was input from World Nuclear Association experts. Secondary data from Brightway2 and ecoinvent 3.8. Build a LCA model with 20 parameters
- **System boundary:** Uranium mining, milling, conversion, enrichment, fuel fabrication, plant construction, operation, decommissioning, interim storage, and final disposal of spent fuel. Reprocessing is excluded.
- **Key findings:** Cradle-to-grave lifecycle per 1 kWh of electricity generated:
 - Default: 6.1 g CO₂-eq/kWh
 - Pessimistic: 122 g CO₂-eq/kWh
- **Main emissions source:** Upstream nuclear fuel processes:
 - Mining and milling: 46% of emissions
 - Conversion, enrichment, and fuel fabrication: 23% of emissions
- **Publication:** Published in Environmental Science & Technology and funded by UNECE and FNR

Comparison

Assumption	KKG / KKL [4]	Parametric LCA [5]
Functional unit	1 kWh at the power plant	1 kWh from a PWR power plant
Reactor type	PWR (KKG) + BWR (KKL)	Generic PWR
Geography	Switzerland (2014–17)	Global average (2020)
System boundary	Cradle-to-grave, open cycle	Cradle-to-grave, open cycle
Modelling approach	Deterministic, plant-specific	Parametric (20 variables)
Lifetime	50 years	60 years
Capacity	3002 / 3600 MWth	1000 MWe
Net efficiency	33.6% / 33.3%	34%
Enrichment level	4.95% / 4.50%	4.15%
Enrichment mix	100% centrifuge	80% centrifuge / 20% diffusion
Software / database	SimaPro 8 / ecoinvent 3.3	Brightway2 / ecoinvent 3.8
Climate change result	5.6 / 9.4 g CO ₂ -eq/kWh	6.06 g CO ₂ -eq/kWh (default model)

Coal-fired Power Plant

Paper 1:

Title: Life cycle and environmental impact assessment of coal-fired power plants in Bangladesh

Year: 2025

Paper 2:

Title: Environmental impact assessment of a remote coal-fired power plant in Central Kalimantan: A life cycle assessment approach to mitigation strategies

Year: 2025

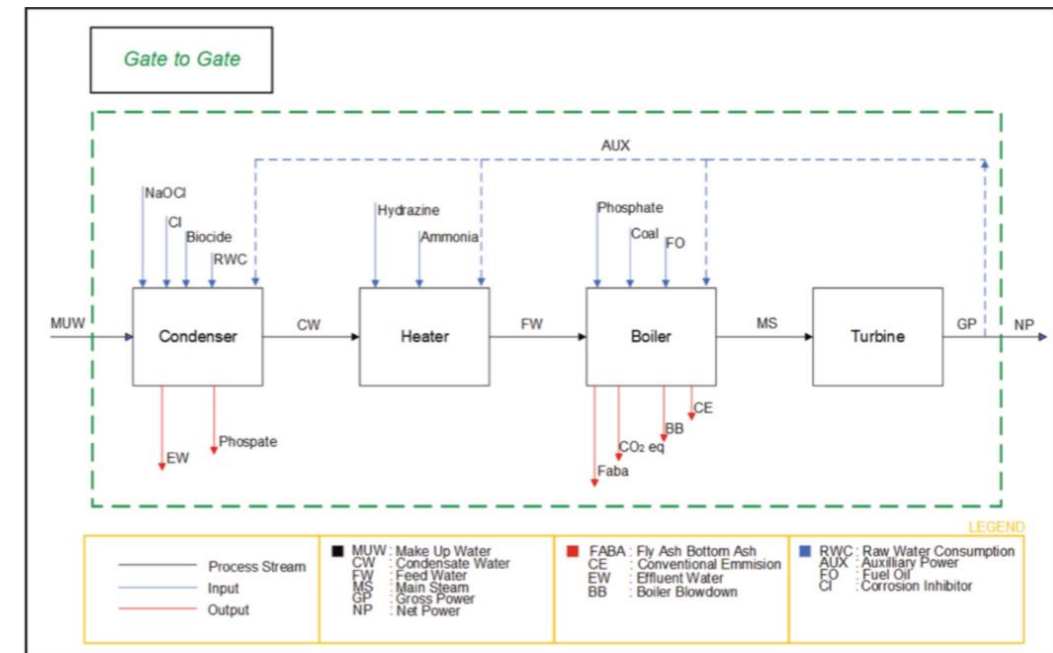
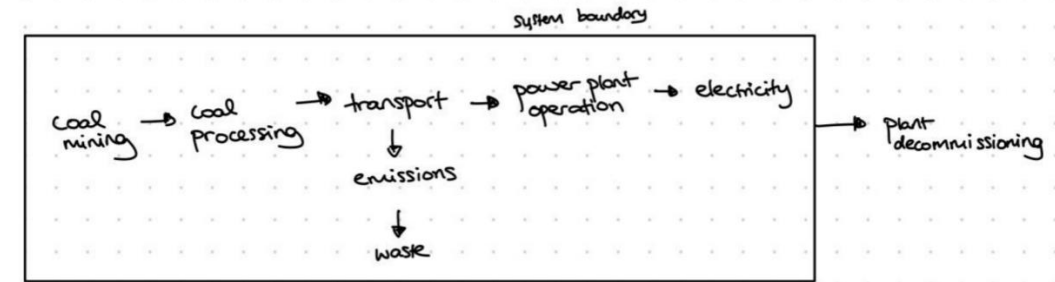
The Papers

Paper 1: Bangladesh

- Lead Bangladesh towards policy for sustainable energy and growing trend demand, evaluate resource use, emissions and impact
- Comparative: Barapukuria (subcritical), Rampal (supercritical) and Payra (ultra-supercritical)
- Data/limitations: Pulls heavily from data sheets (such as Ecoinvent), Cradle-to-Gate

Paper 2: Indonesia

- Help reach frameworks such as the Paris Agreement, quantify existing emissions and identify strategies for minimising future emissions
- Not comparative
- Data/limitations: 99% actual data from the power plant, Gate-to-Gate



Results (in kWh) & Comparison

Impact category	Paper 1	Paper 2
Global Warming Potential (GWP)	- 0.765-0.767 kg CO ₂ -eq (Barapukuria) - 0.826-0.828 kg CO ₂ -eq (Rampal) - 0.841-0.843 CO ₂ -eq (Payra)	1.29 kg CO ₂ -eq
Acidification Potential (AP)	0.0015-0.0032 kg SO ₂ -eq	0.00221 kg SO ₂ -eq
Eutrophication Potential (EP)	0.00015-0.00045 kg PO ₄ -eq	0.0131 kg PO ₄ -eq
Particle Matter Formation	0.0008-0.0015 kg PM _{2.5} -eq	-
Water consumption / Resource depletion	0.0012-0.0015 m ³	-
Ozone depletion	-	0.0000000304 kg CFC-11 eq

- Both targeted at researchers and engineers
- Different units

- Different system boundaries
- Database vs real data

Comparison between the three technologies

Category	Solar PV – LCA 1	Nuclear – LCA 1	Coal – LCA 2
Study focus	20 MWp grid-connected PV plant in Hungary	Swiss nuclear power plants: Gösgen and Leibstadt	Remote coal-fired power plant in Central Kalimantan, Indonesia
Purpose	Electricity generation from a PV park	Electricity generation from nuclear power	Electricity generation from coal combustion
Functional unit	1 kWh AC electricity generated	1 kWh electricity generated at the power plant	1 kWh electricity generated
System boundary	Cradle-to-grave	Cradle-to-grave	Gate-to-gate
Included stages	PV module production, mounting structure, inverters, cables, transport, installation, operation, maintenance, end-of-life treatment	Uranium mining, milling, conversion, enrichment, fuel fabrication, construction, operation, decommissioning, radioactive waste storage	Plant operation, coal combustion, water and chemical inputs, operational emissions
Excluded stages	Capital equipment, commuting, administration, marketing, R&D, decommissioning energy	Fuel reprocessing	Coal mining, coal transport, plant construction, infrastructure, decommissioning, end-of-life
Main GWP result	6.02 g CO ₂ -eq/kWh (simplified); 6.57 g CO ₂ -eq/kWh (detailed)	5.6 g CO ₂ -eq/kWh for KKG; 9.4 g CO ₂ -eq/kWh for KKL	1.29 kg CO ₂ -eq/kWh
Geography	Hungary / European data	Switzerland	Indonesia
Main data sources	Primary plant data + ecoinvent 3.5	Primary plant data + ecoinvent 3.3	99% plant data + ecoinvent for missing data
LCIA method / software	PEF methodology	SimaPro 8	OpenLCA