SIXTH FRAMEWORK PROGRAMME
[6.1]
[Sustainable Energy Systems]

Life cycle based approaches for the assessment of innovative energy technologies

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External Costs of Energy Technologies
Brussels, February 17, 2009

Key findings

- Life cycle thinking is indispensible in energy policy
- Technology development in LCA background matters
- Energy policy and environmental sustainability assessment should consider possible future situations
- The NEEDS LCI project results provides relevant knowledge
- Transparent unit process LCI databases are one important prerequisite to provide policy relevant answers

Outline

- The challenge of technology assessment
- NEEDS Project: Goal, Partners & Tasks
- Far future LCI modelling
- Results
- Conclusions

The challenge of technology assessment

- We know the environmental impacts of today's electricity production
- We can quantifiy external costs of pollution
- We can model the optimal energy supply situation in Europe under given constrains
- We have reference LCI data available (e.g. Japanese database, US database or international ecoinvent Database)
- How to combine this knowledge for environmental sustainability assessment of the European energy supply?

Goal of the NEEDS-Project

Evaluate the:

- full costs and benefits (i.e. direct + external)
- of energy policies and
- of future energy systems
- at the level of individual countries and
- for the enlarged EU

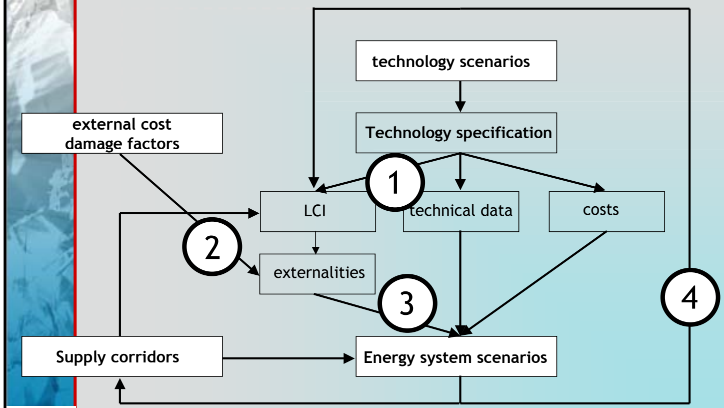
Identification of external costs, based on Life cycle inventories (LCI)

3 scenario families:
- Business as Usual,
- 440ppm CO_2,
- Renewables and Energy Efficiency

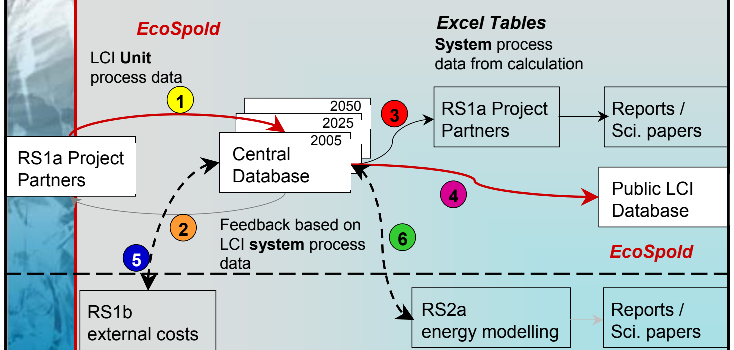
3 time horizons:
2000, 2025, 2050

External costs per group of countries

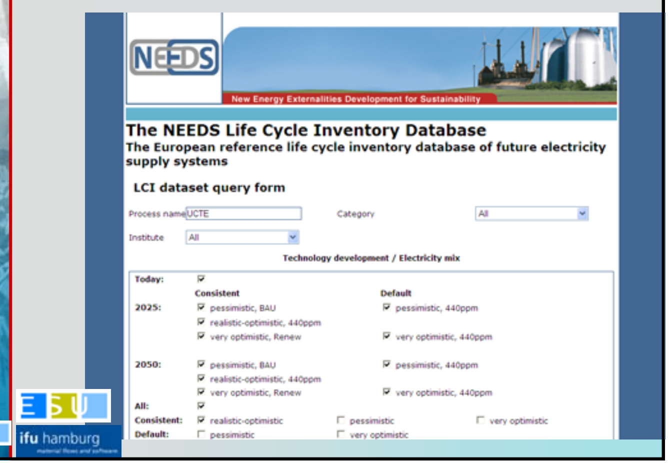
Interactions between the disciplines



Work flow and products



NEEDS LCI database



NEEDS LCI database

Your search results: (11 matches)

HTML = View dataset in browser, **XLS** = Download dataset als Excel file, **XML** = Download dataset as XML

Process name: electricity, at offshore wind park 752MW
Scenario: 2025, pessimistic, 440ppm **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 752MW
Scenario: 2025, pessimistic, BAU **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 1068MW
Scenario: 2025, realistic-optimistic, 440ppm **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 1332MW
Scenario: 2025, very optimistic, 440ppm **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 1332MW
Scenario: 2025, very optimistic, Renew **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 1440MW
Scenario: 2050, pessimistic, 440ppm **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 1440MW
Scenario: 2050, pessimistic, BAU **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 1944MW
Scenario: 2050, realistic-optimistic, 440ppm **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 2496MW
Scenario: 2050, very optimistic, 440ppm **Unit:** kWh, **Location:** DK — HTML | XLS | XML

Process name: electricity, at offshore wind park 2496MW
Scenario: 2050, very optimistic, Renew **Unit:** kWh, **Location:** DK — HTML | XLS | XML

EcoSpold Files: Meta information

Meta information	electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]
Process information	*electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]*
Reference function	**electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]**
Dataset relates to product	Yes
Name	electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW
Local name	Strom, Parabolspiegel, ab Kraftwerk, DNI2000, mit Speicher, 46MW
Infrastructure process	No
Amount	1
Unit	kWh
Category	solar thermal systems
Subcategory	power plants
Local category	Solarthermie
Local subcategory	Kraftwerke
Included processes	Production of solar electricity by a parabolic trough (Andasol I), 46 MW, including collector, buidling, conventional parts, steamturbine, dismantling and operation materials
Infrastructure included	Yes
Synonyms	0
Geography	**electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]**
Location	MA
Text	South Spain. Guadix. DNI: 2000 kWh/(m2*a)
Technology	**electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]**
Text	Best available technique according to validated and revised data from Lechon 2006 (orginial data from company)
Time period	**electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]**
Data valid for entire period	Yes
Text	Time of publications.
Start year	2007

EcoSpold Files: LCI data

Flow data — **electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]**

Exchanges — *electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]*

From Nature — **electricity, solar thermal, at solar trough, DNI2000, with storage, 46MW, MA, [kWh]**

Number	Name	Location	Infra	Mean value	Unit	Uncertainty type	SD95%
resource/biotic							
157	Energy, gross calorific value, in biomass		No	8.84504e-3	MJ		
56	Peat, in ground		No	9.07355e-7	kg		
47	Wood, hard, standing		No	1.19424e-7	m3		
154	Wood, soft, standing		No	7.89504e-7	m3		
31	Wood, unspecified, standing		No	1.37783e-11	m3		
resource/in air							
37	Carbon dioxide, in air		No	7.88507e-4	kg		
61	Energy, kinetic, flow, in wind		No	7.36541e-4	MJ		
147	Energy, solar		No	2.44900e1	MJ		
resource/in ground							
75	Aluminium, 24% in bauxite, 11% in crude ore, in ground		No	1.12492e-5	kg		
32	Anhydrite, in ground		No	2.24519e-8	kg		
88	Barite, 15% in crude ore, in ground		No	1.05408e-5	kg		
158	Basalt, in Boden		No	5.09885e-5	kg		
139	Borax, in ground		No	2.19401e-7	kg		
101	Calcite, in ground		No	3.59639e-3	kg		
97	Chromium, 25.5 in chromite, 11.6% in crude ore, in ground		No	3.94810e-5	kg		
51	Chrysotile, in ground		No	4.54850e-10	kg		
140	Cinnabar, in ground		No	3.63924e-11	kg		
44	Clay, bentonite, in ground		No	5.14355e-5	kg		
15	Clay, unspecified, in ground		No	1.07401e-3	kg		

Advanced Fossil (including CCS)

Fossil fuel power plants:

- Hardcoal (350W / 600MW / 900MW)
- Lignite (950MW)
- Natural gas (50MW / 500MW)

Carbon Capture and Storage (CCS):

- Capture: post-combustion and oxy-fuel combustion processes
- Storage: in depleted gasfields or aquifer, different transport-distances (200km / 400km)

Advanced Nuclear

Next generation nuclear power:

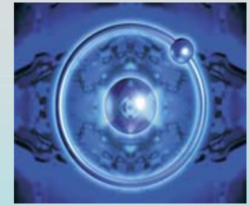
- *Nuclear Power Plant of the 3th generation:* European Pressurized Reactor (EPR) (1000 MW)
- *Nuclear Power Plant of the 4th generation:* Sodium cooled fast breeding Reactor (1450 MW) with recycling of Plutonium

Hydrogen

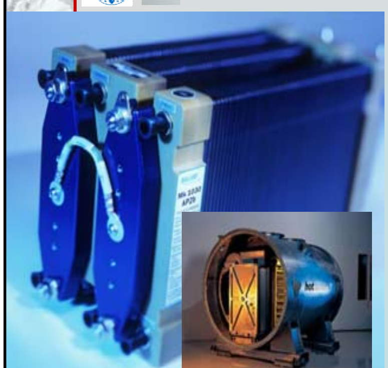
Icelandic New Energy
Promoting Hydrogen in Iceland

Hydrogen:

- Designed for mobile and remote island electricity generation
- Compressed gaseous hydrogen at hydrogen fuelling station by electrolysis
- Including materials needed for production, construction, operational and disposal processes



Fuel Cells



PEMFC
Proton exchange membrane fuel cell

- 2kW stack size

MCFC *Molten Carbonate Fuel Cell*

- 250 kW based on the MTU HotModule project with Woodgas / Natural gas
- MCFC: 2000 kW hybrid

SOFC *Solid Oxide Fuel Cell, SOFC*

- 1 kW planar
- 300 kW CHP tubular
- 2000 kW CHP hybrid

Photovoltaic

AMBIENTEITALIA

c-Si technologies

- sc-Si (plant size / integrated roof)
- c-Si ribbon (plant size / integrated roof)

Thin films

- Cadmium Telluride (CdTe)

New concept devices

- GalnP/GaAs Concentrators

Conditions and scope

- Southern Europe vs. Central Europe
- Includes the Balance of System (e.g. converter, standing, cable, etc.)

Wind offshore

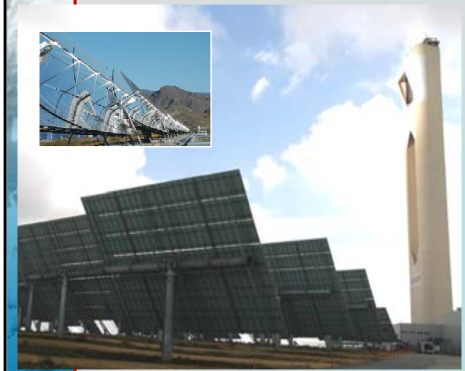
Capacity

- today: 2 MW
- future: up to 32 MW

Construction

- Steel tower / concrete tower
- Combined with waterturbine, wave generator or similar - with shared cable to continent

Solar thermal power plant



Capacity

- Today: pilot plant (tower) with 10 MW
- Future: up to 400 MW with Fresnel Lenses and salt storage

Construction

- Concepts: Trough / Tower / Fresnel
- Co-generation for cooling / desalination

Solar thermal power plant: Seville, Spain

Biomass

Biomass-production:

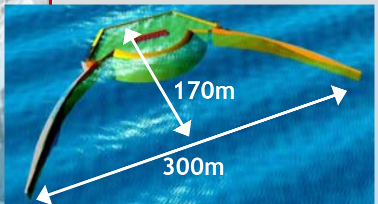
- Straw (direct combustion)
- Residual wood (gasification)
- Short-rotation forestry (direct comb., gasification)

Technologies:

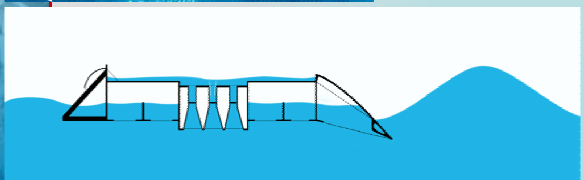
- Optimal direct combustion
- Biomass within IGCC
- Pyrolysis with combustion engine
- Gasification with fuel cell

Wave energy

Wave Dragon



- steel & concrete: 33'000 t
- Height above sea level: 3-7 m
- Capacity: 20 MW
- power production:
  20 GWh / year / unit



Wave energy

Wave Dragon

Background data

- Background Data
  - *year 2000:*
    ecoinvent data v1.3 (ca. 2700 international, quality controled Datasets)
  - *years 2025 and 2050 :*
    ecoinvent data including modified LCIs of selected datasets
- Modified Datasets in future scenarios
  - metals, mineral building materials, transports, electricity mixes

Adapted background data
Example: Wind energy

- A typical wind power plant is
  - in 2000: 600 kW, onshore
  - in 2050 : 2 MW, offshore
- Most relevant materials:
  - stainless steel 18/8
  - copper

⇒ Change in LCI background data in view of situation in 2025 / 2050:
copper, ferronickel, pig iron, sinter

Cradle to gate (rolled-up) data

- cumulative emissions and resource consumptions
- “all inclusive” data: (impacts due to resource extraction, refining, shipping, product manufacture, transports)
- intransparent: no adjustments possible
- matter of belief: no independent quality check possible

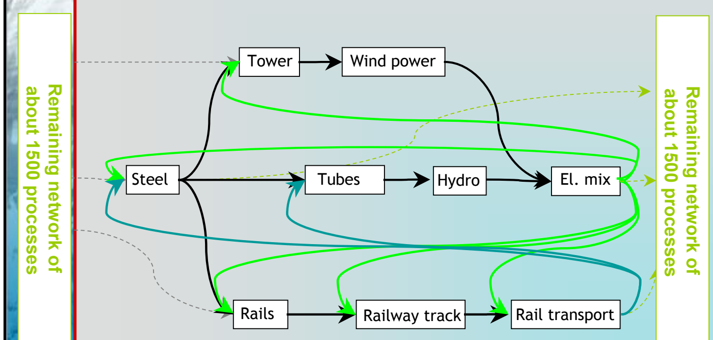
		Manganese	Copper
	Unit	kg	kg
Resources			
Land use II-III	m2a	0.491	0.215
Land use Benthos II-III	m2a	0.0273	0.0571
Land use II-IV	m2a	0.0331	0.0232
Land use III-IV	m2a	0.00352	0.00855
Land use IV-IV	m2a	1.80E-05	0.00135
Wood	t	1.57E-05	1.01E-05
Potential energy water	TJ	7.11E-06	3.49E-06
Lignite	kg	1.61	0.718
Hard coal	kg	1.27	0.773
Natural gas	Nm3	0.22	0.579
Crude oil	t	0.000318	0.000656
Uranium	kg	0.000109	5.00E-05
Water Wasser	kg	3.77E+04	1.82E+04
Limestone	kg	0.0313	0.028
Gravel	kg	0.0744	0.53
Iron	kg	0.0145	0.0161
Copper	kg	0.00116	1
Emissions to air			
Waste heat	TJ	0.000106	9.42E-05
Carbon dioxide	kg	5.1054	5.2106
Sulphur dioxide	kg	0.0305	0.136
Nitrogen oxides	kg	0.00974	0.008
Methane	kg	0.00941	0.0102
NMVOC	kg	0.00307	0.00604
BTEX-aromatics	kg	5.42E-05	5.52E-05
Benzo(a)Pyrene	kg	3.21E-09	8.45E-09
Radon-222 (including Radium-226)	kBq	6.01E+03	2.75E+03
Emissions to water			
Chlorides	kg	0.0219	0.0255
Sulphates	kg	0.0214	0.0115

Unit process data

- direct requirements and emissions
- all individual steps accessible
- full transparency: independent quality check possible
- full flexibility: adjustments easily possible

		Manganese	Copper
	Unit	kg	kg
Resource input			
Land use II-III	m2a	0.084	0.018
Land use II-IV	m2a	0.025	0.006
Copper, at ore	kg		1
Manganese, at ore	kg	1	
Technosphere input			
hard coal coke	TJ		3.00E-06
electricity, at medium voltage, UCTE	TJ	3.58E-05	1.54E-05
blasting	kg	0.004	
Transport lorry 40 t	tkm		0.1
Transport railway	tkm		0.2
Diesel in building machine	TJ	9.60E-07	
light fuel oil in boiler	TJ		1.90E-05
natural gas in industrial boiler	TJ		1.60E-05
waste, in residual material landfill	kg		2
Emissions to air			
waste heat	TJ	3.58E-05	1.84E-05
Cadmium	kg		8.00E-06
carbon dioxide	kg		0.3
Particulate matter	kg		0.0006
Lead	kg		1.50E-05
Sulphur dioxide	kg		0.12
Zinc	kg		0.00012

The advantage of unit process databases:
Interdependency & Feedback-Loops



Consistent environmental sustainability assessment

- NEEDS processes are linked to each other: Unit process level required
- Interdependency of energy generation, material production and transport technologies
  ⇒ one single change affects all other systems
- consistent modelling of possible futures (scenarios):

electricity mix	technology development
business as usual	pessimistic
CO_2 cap at 440ppm	realistic optimistic
Renewables	very optimistic

future off-shore wind technologies

	2050
'pessimistic'	- 16 MW turbine, guyed foundation - Carbon fibre tower - 75% carbon fibre + 25% natural fibre blades - Gearbox upscale
'realistic-optimistic'	- 24 MW turbine, floating foundation - Gearless turbine - Carbon fibre lattice tower - Co-existence with water turbine/wave generator; shared cables to shore
'very optimistic'	- 32 MW turbine - Hydro-windturbine - Off-shore 'energy landscape'

Source: NEEDS, DONG Energy

Adapted EU electricity mix

EU-Mix in 2000

- 46.8% fossil
- 35.7% nuclear
- 15.7% hydropower
- 1.8% new renewables and waste

- production mix of EU-15
- share based on annual production of selected countries

EU-Mix in the future (440ppm)

- 54.3% fossil
- 23.3% nuclear
- 19.0% hydropower
- 3.4% new renewables and waste

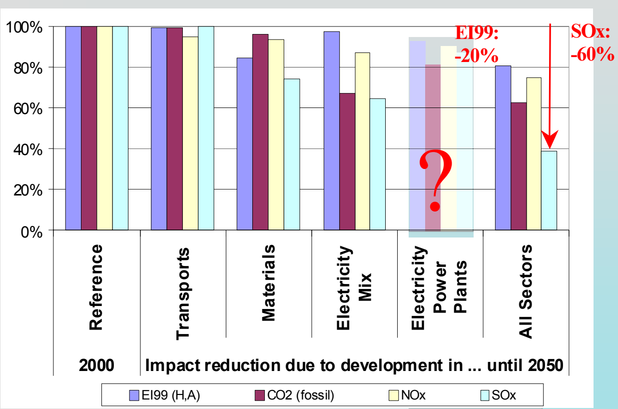
- production mix of technologies
- share based on PAN-Model of selected power plant capacities
- CO_2-concentration: max 440 ppm

EU-Mix in the future (Renewables)

- 19.6% fossil
- 0.0% nuclear
- 24.3% hydropower
- 56.1% new renewables and waste

- production mix of technologies
- shares based on DLR-study for OECD-countries

Impacts are reduced due to …



LCI Results

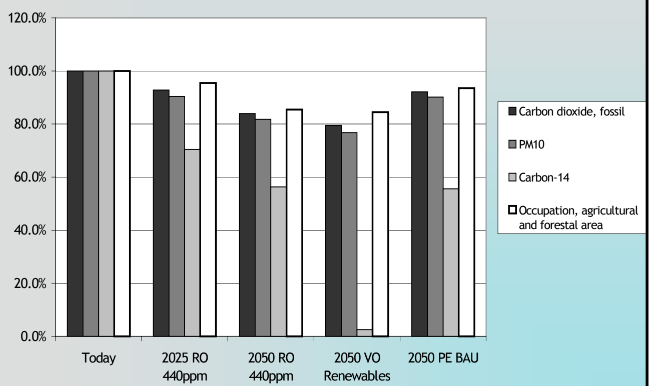
- Electricity generating technologies, based on non renewable and renewable primary energy sources
- Elementary flows shown:
  - Carbon dioxide, fossil, to air
  - particulate matter, to air
  - Carbon-14, to air
  - land use (agricultural and forestal)
- Development within technologies
- Comparison between technologies

Scenarios shown

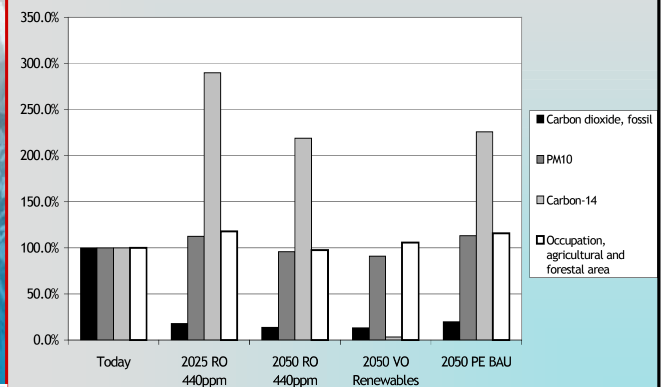
Name	Time	Technology development	electricity mix
TODAY	2000	current state	current European electricity mix (UCTE)
2025 RO, 440ppm	2025	realistic optimistic	440ppm CO_2 cap
2050 RO, 440ppm	2050	realistic optimistic	440ppm CO_2 cap
2050 VO, RENEW	2050	very optimistic	increased renewables and energy efficiency
2050 PE, BAU	2050	pessimistic	business as usual

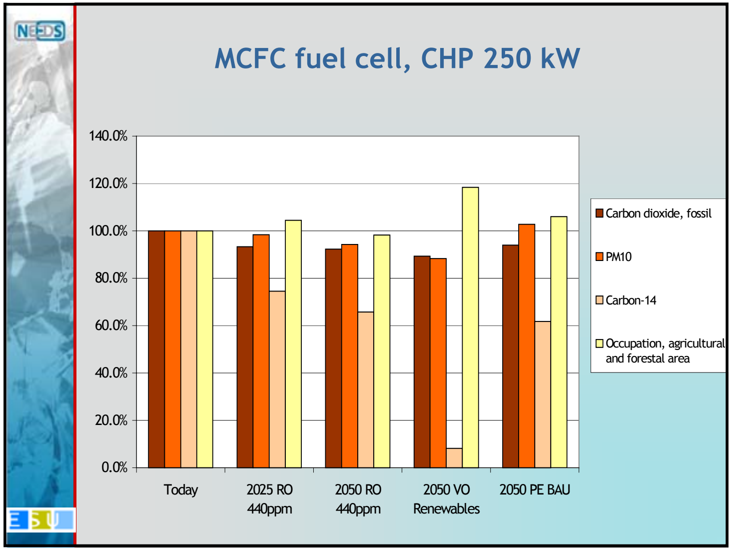
Development within technologies

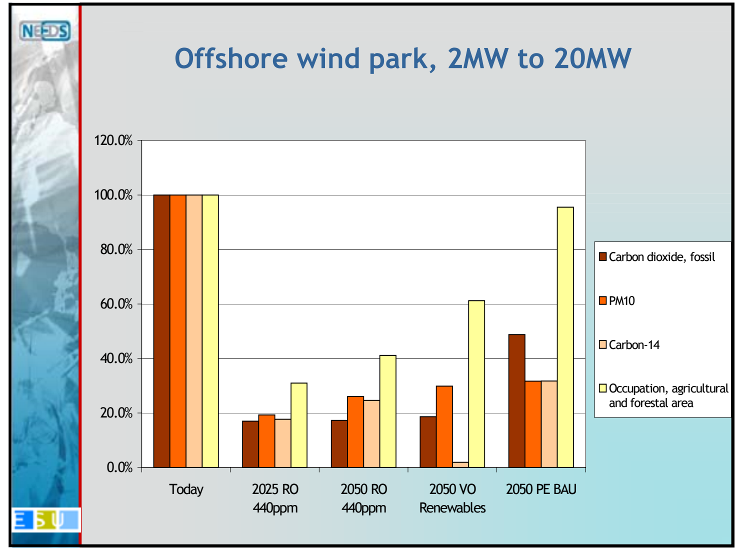
Hard coal power plant, 800 MW

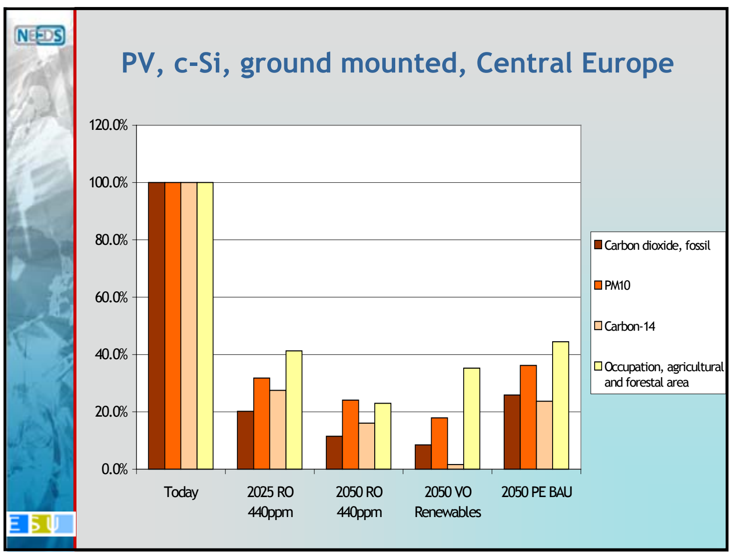


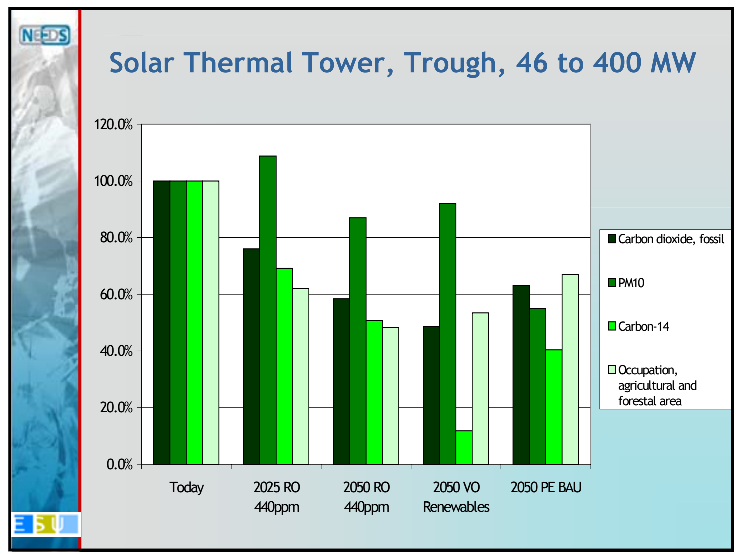
Hard coal power plant, 500 MW, post CCS, 200km, 2500m, gasfield



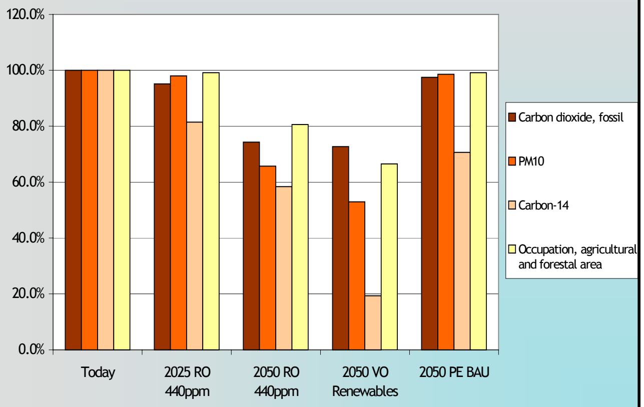

NEEDS
MCFC fuel cell, CHP 250 kW
140.0%
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU
Carbon dioxide, fossil
PM10
Carbon-14
Occupation, agricultural and forestal area
ESU


NEEDS
Offshore wind park, 2MW to 20MW
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU
Carbon dioxide, fossil
PM10
Carbon-14
Occupation, agricultural and forestal area
ESU

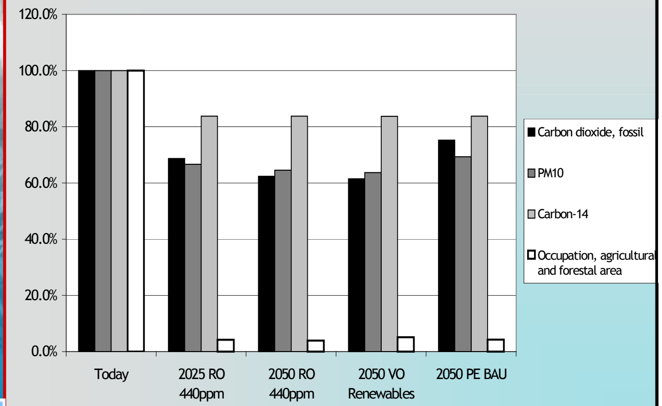

NEEDS
PV, c-Si, ground mounted, Central Europe
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU
Carbon dioxide, fossil
PM10
Carbon-14
Occupation, agricultural and forestal area
ESU


NEEDS
Solar Thermal Tower, Trough, 46 to 400 MW
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU
Carbon dioxide, fossil
PM10
Carbon-14
Occupation, agricultural and forestal area
ESU

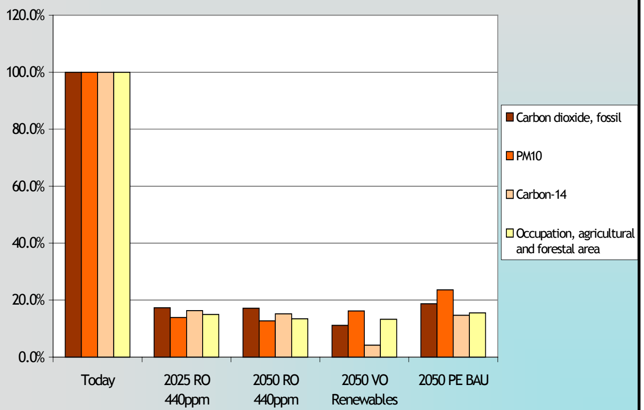
Biomass (poplar) steam turbine



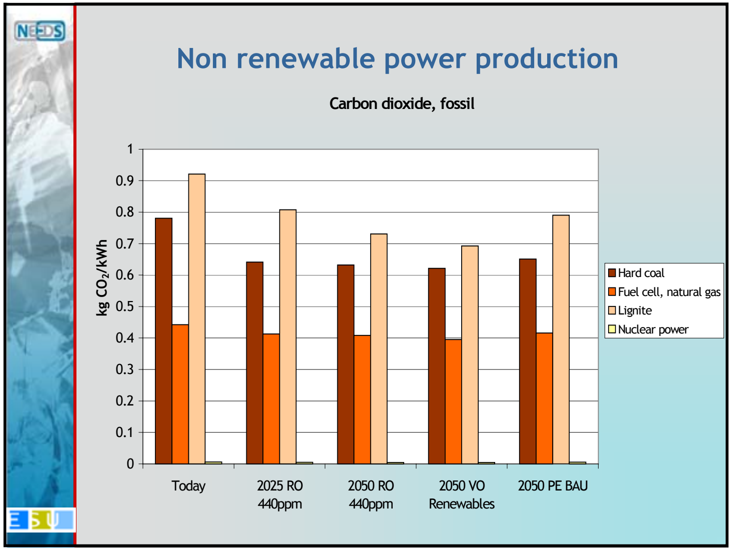
Nuclear power, 2nd and 3rd generation

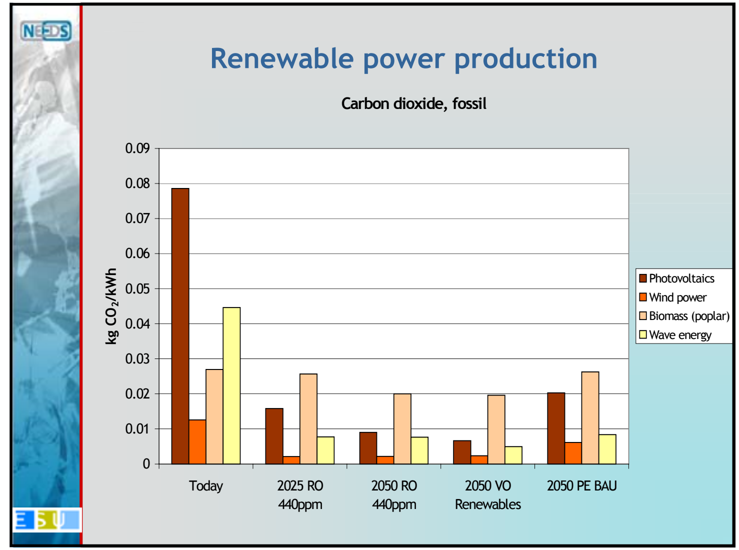


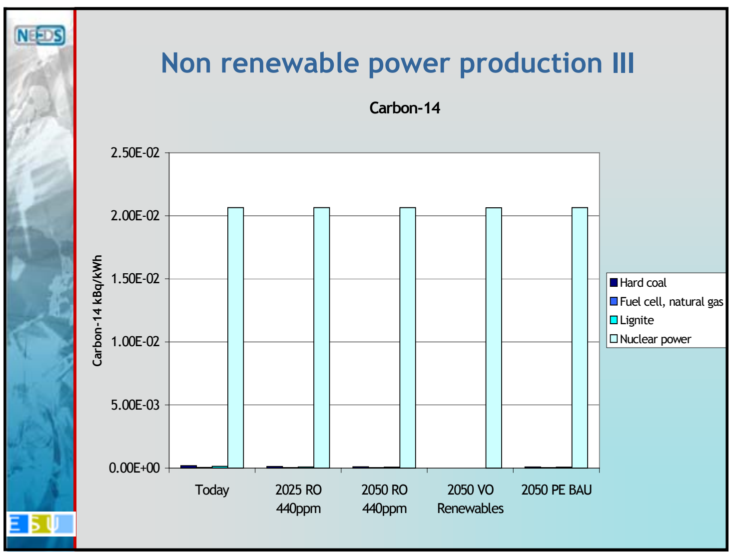
Wave energy (wave dragon), 350kW / 7MW

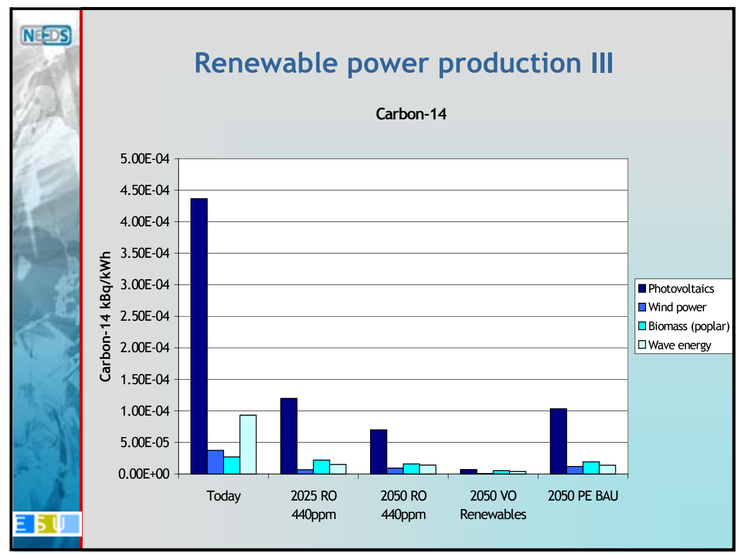


Comparison between technologies

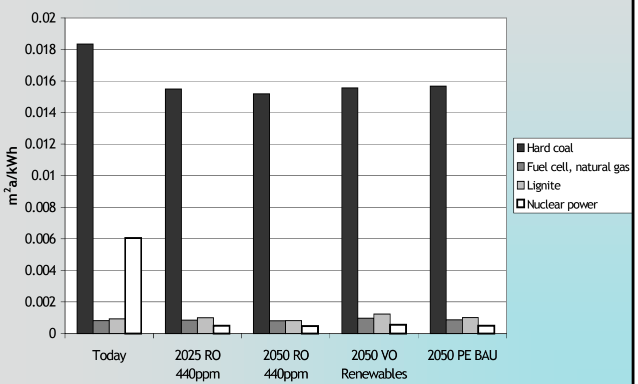

Non renewable power production
Carbon dioxide, fossil
kg CO_2/kWh
Hard coal
Fuel cell, natural gas
Lignite
Nuclear power
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU


Renewable power production
Carbon dioxide, fossil
kg CO_2/kWh
Photovoltaics
Wind power
Biomass (poplar)
Wave energy
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU

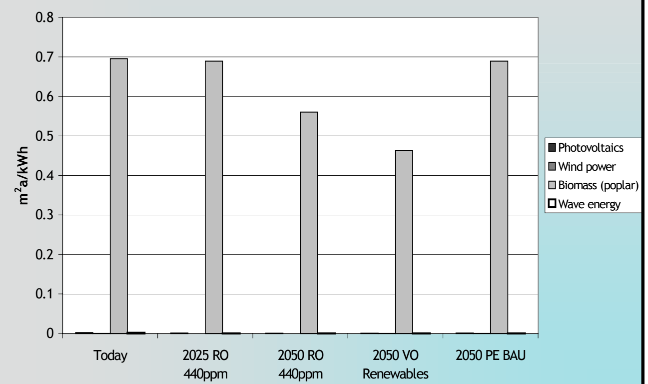

Non renewable power production III
Carbon-14
Carbon-14 kBq/kWh
Hard coal
Fuel cell, natural gas
Lignite
Nuclear power
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU


Renewable power production III
Carbon-14
Carbon-14 kBq/kWh
Photovoltaics
Wind power
Biomass (poplar)
Wave energy
Today
2025 RO 440ppm
2050 RO 440ppm
2050 VO Renewables
2050 PE BAU

Non renewable power production IV



Renewable power production IV



Observations

- each technology has his environmental Achilles' heel
- improvement potential until 2050 between 20% to >90%
- operation intensive systems show less improvement potentials, unless end of pipe technologies are installed (e.g. Carbon Capture and Storage)
- With time, some technologies outperform others (e.g. PV vs. wood)
- In some cases (wind power) increase in emissions after 2025 due to change in design
- excluding electricity mix developments leads to substantially different results

Conclusions

- Life cycle thinking is indispensible in energy policy
- Technology development in LCA background matters
- Energy policy and environmental sustainability assessment should consider possible future situations
- The NEEDS LCI project results provides relevant knowledge
- Transparent unit process LCI databases are one important prerequisite to provide policy relevant answers

Thank you very much for your attention!

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Acknowledgements:

European Commission, 6th framework program

Research teams of NEEDS Research stream 1a