REflex
Analysis of the
European Energy System

LIFE CYCLE ASSESSMENT OF FUTURE ENERGY SYSTEMS -WIND POWER AS A CASE STUDY

KIT-ITAS

- **Lei Xu**
- **Maryegli Fuss**
- **Witold-Roger Poganietz**

REFLEX-Expert Workshop-08.11.2017

Energy system scenarios and LCA modelling

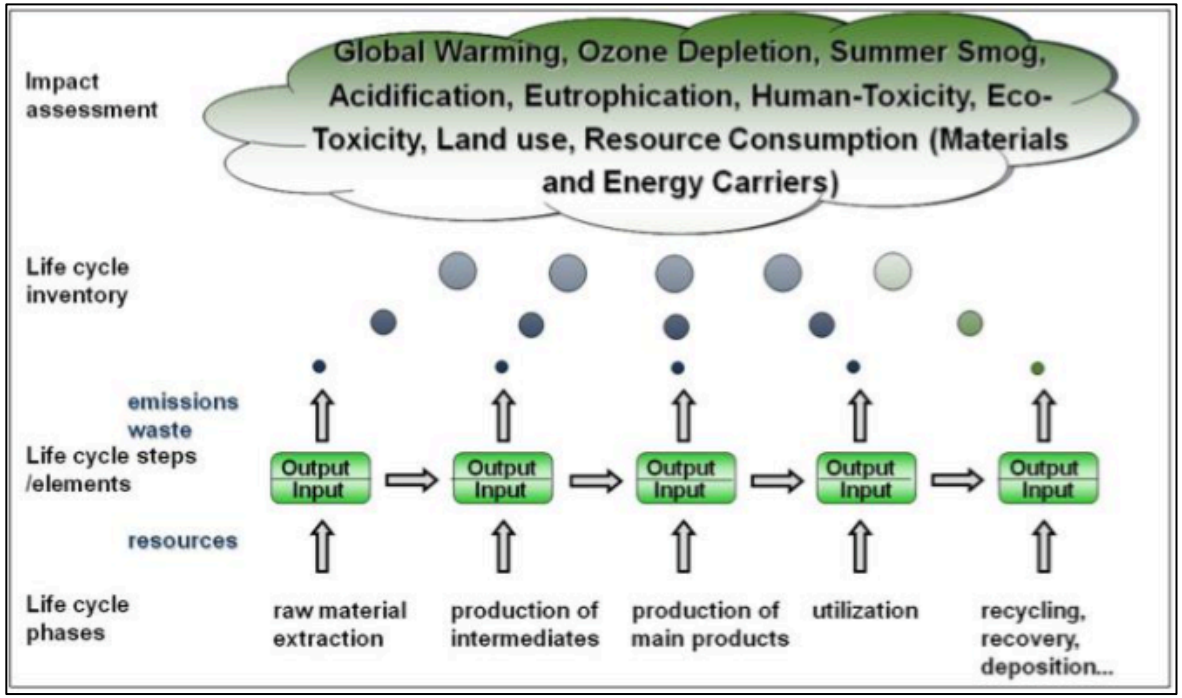
The main challenge of coupling energy system modelling and life cycle assessment

generation (in GWh)								
wind	*w-onshore*	*w-offshore*	*solar*	*solar ground mounted*	*solar rooftop*	*Biomass-waste*	*Hydro (pumping excluded)*	*Geothermal and other renewables*
343.105	240.173	102.931	122.016	97.612	24.403	84.639	26.435	1.880
1.846.984,04	1.282.348,61	564.635,43	753.903,51	603.061,17	150.842,34	441.929,07	359.070,20	30.564,03

Aggregated data and different data source

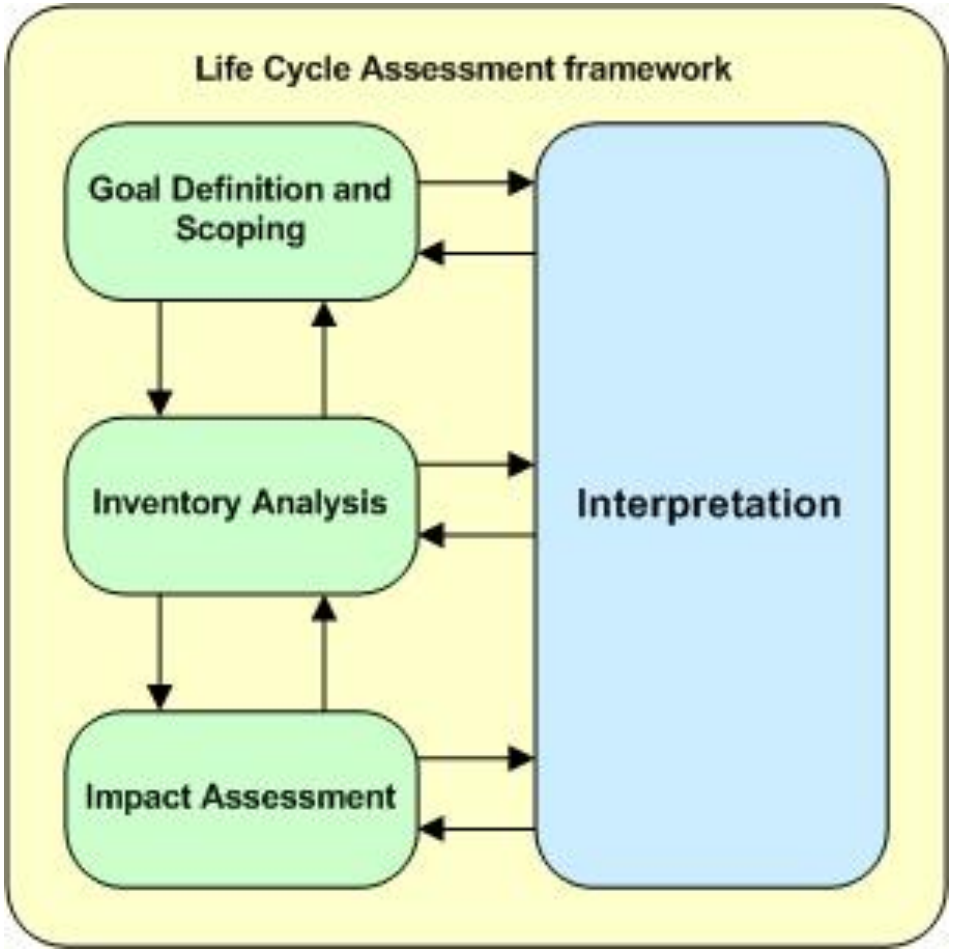
Methodology

- LCA（Life Cycle Assessment）presents the environmental impacts of a product or a service, within a whole life cycle, from material acquisition to the processes of production, utilization, recycling and disposal.
- “From cradle to grave”



Overview of Life Cycle Assessment *(source: PE International, 2010)*

LCA methodology



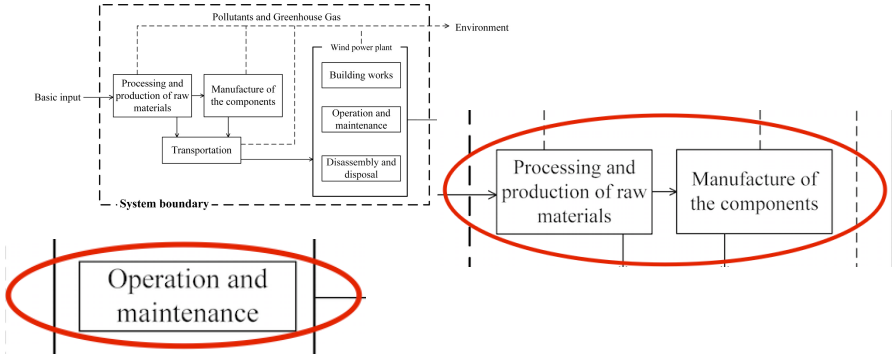
From inventory analysis to LCA impacts

Items	Materials	Quantity (t) per transformer	Quantity (t) in total
Box-type transformers	Copper	1.6	28.8
1600KVA	Steel	5.3	95.4
(For 1.5MW wind turbines)	Silica	0.2	3.6
Box-type transformers	Copper	1.6	48
800KVA	Steel	5.3	159
(For 0.75MW wind turbines)	Silica	0.2	6
Step-up transformer	Copper	11	11
	Steel	40	40
	Silica	2.4	2.4
Cables	Copper		130.7

Components of transformers and cables

Items	Subcomponents	Materials	Quantity (t) per turbine	Quantity (t) in total
Rotor	Three blades	Fiberglass	6.6	119.4
		Resin	10.0	179.2
	Blade hub	Cast iron	6.1	110.4
	Pitch system	Steel	1.9	34.7
Nacelle	Bed frame	Cast iron	5.5	98.6
	Nacelle cover	Fiberglass	1.2	21.6
		Resin	1.8	32.4
	Yaw system	Steel	2.3	40.9
Generator	Generator rotor	Magnetic steel	11.1	200.5
	Generator stator	Copper	19.9	358.9
	Fixed axis	Cast iron	3.9	70.3
	Drive shaft	Cast iron	5.2	94.4
Tower	Steel, low alloyed	Steel	101.5	1826.8

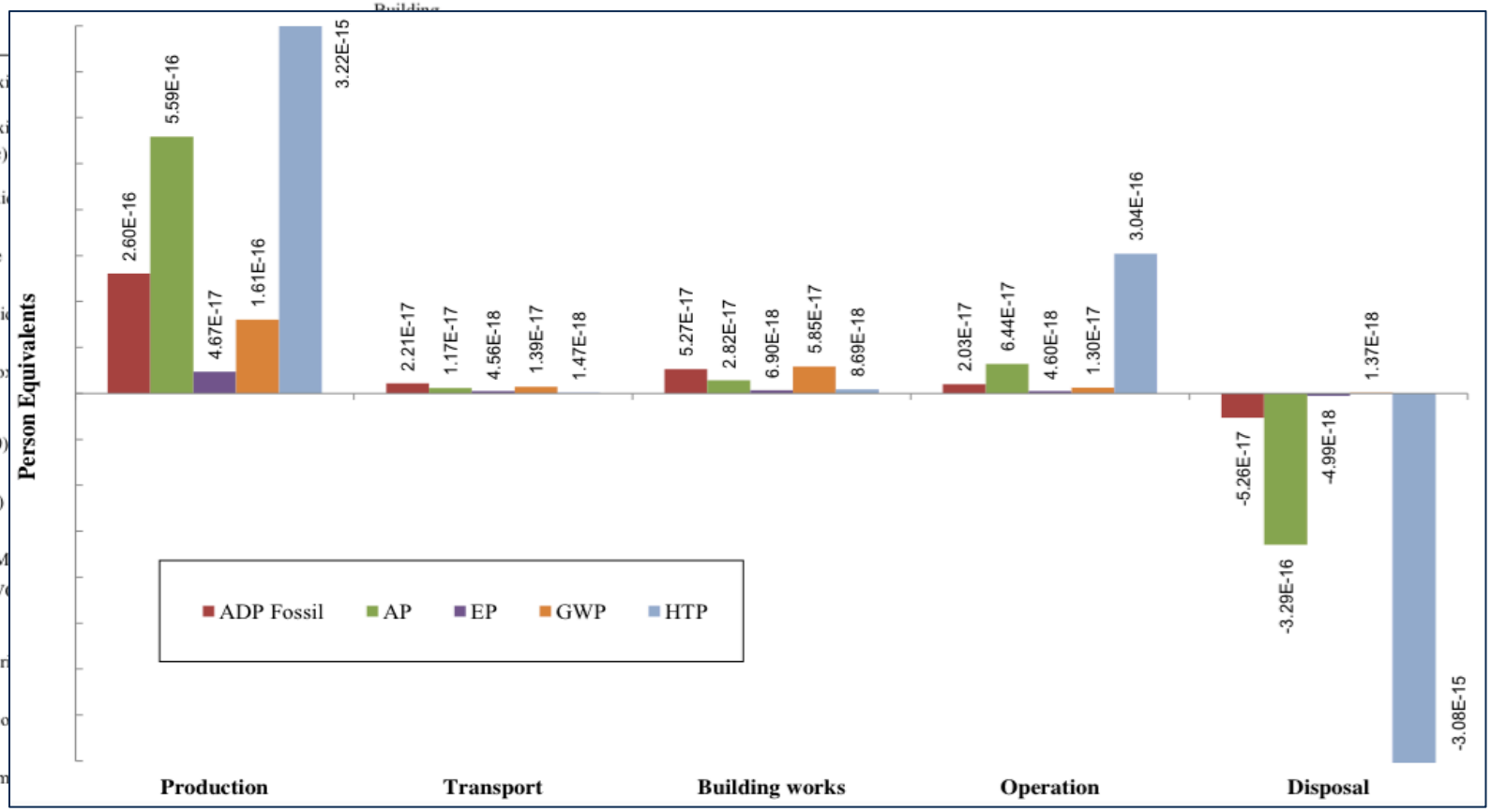
Components of the Goldwind GW77/1500kW wind turbine



Items	Subcomponents	Materials	Quantity (t) per turbine	Quantity (t) in total
Rotor	Three blades	Fiberglass	4.1	122.4
		Resin	6.1	183.6
	Blade hub	Cast iron	4.5	135
	Pitch system	Steel	1.8	54
Nacelle	Base frame	Steel	5.5	165
	Main shaft	Steel	2.2	66.3
	Gearbox	Cast iron	3.2	96
		Steel	3.2	96
	Generator	Silica	0.1	3.6
		Copper	1.4	40.5
		Steel	2.8	84.6
	Yaw system	Steel	2.3	69
	Nacelle cover	Fiberglass	0.7	21
		Resin	1.1	33
Tower	Steel, low alloyed	Steel	55.4	1662

Components of the Goldwind S50/750kW wind turbine

From inventory analysis to LCA impacts of wind electricity



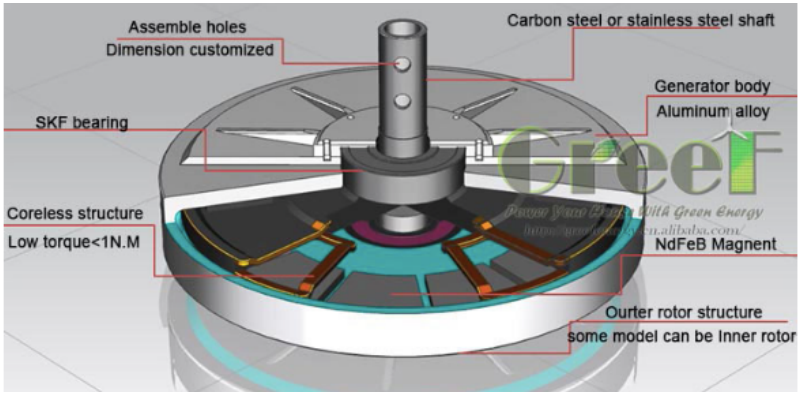
The normalized environmental impacts of 1kWh electricity production classified according to life cycle processes

Hydrogen	6.89E-07	5.88E-07	5.52E-10	8.31E-10	1.55E-07	-5.61E-08
Methane (biogenic)	4.09E-07	2.07E-07	1.11E-09	1.52E-08	4.67E-08	1.38E-07

Emissions to air per kWh electricity production

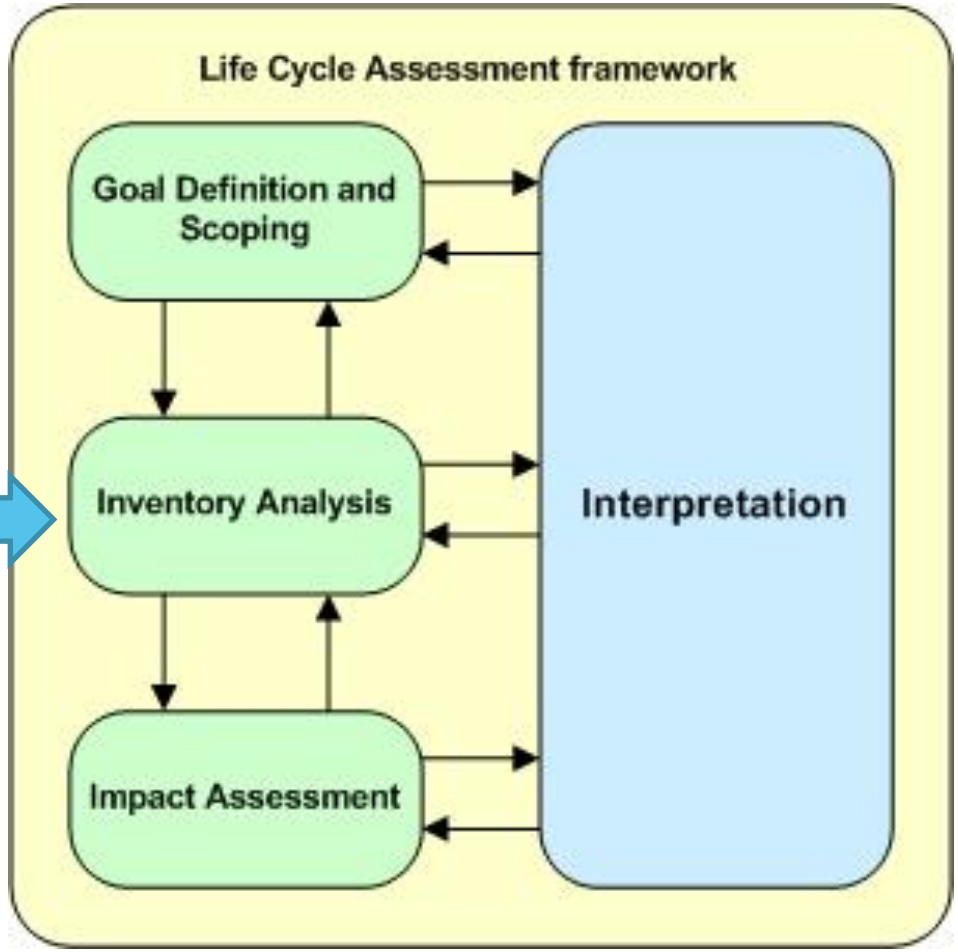
2. Update reference LCIs, e.g. wind-onshore

- Upscaling in the future, i.e. the size of rotor blades, etc. increase in the future, but less material per unit is consumed.
- Carbon fibers will be more competitive and staring to replace glass fibers.
- Economically, permanent magnet generators have become increasingly competitive, though wind turbines of the current generation typically do not use permanent magnets. 20% of the next generation wind turbines would use rare-earth permanent magnets.



Ex-post LCA assessment

Ex-ante assessment
How?



Life cycle inventories (Utopia)

	Data	Data sources
	Overall basic data (reference LCI)	Eco invent Literature review
Foreground	Updating: Materials consumption for promising technologies, i.e. wind, solar Quantity of energy services Generation capacity and life time Fuel consumption Generation efficiencies, etc.	Literature review Company reports Assumptions ESMs (Input)
	Overall basic data	Eco invent database
Background	Updating: Energy mix, e.g. electricity mix, heat mix. E-mobility data Energy mix (rest of the studied geographical and technological scope) Technological improvement related to material production, infrastructure, etc.	Literature review ESMs (Output) Other ESMs Assumptions

Life cycle inventories (Utopia)

	Data	Data sources
Foreground	Overall basic data (reference LCI)	Eco invent Literature review
	Updating: Materials consumption for promising technologies, i.e. wind, solar Quantity of energy services Generation capacity and life time Fuel consumption Generation efficiencies, etc.	Literature review Company reports Assumptions ESMs (Input)
Background	Overall basic data	Eco invent database
	Updating: Energy mix, e.g. electricity mix, heat mix. E-mobility data Energy mix (rest of the studied geographical and technological scope) Technological improvement related to material production, infrastructure, etc.	Literature review ESMs (Output) Other ESMs Assumptions

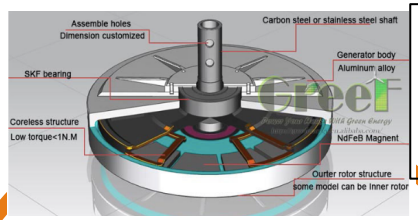
Example: LCA model for wind onshore technology

1. Wind turbine construction, 2 MW onshore

- 1: Identify tecnology process
- 2: Identify potential materials

Database: Ecoinvent 3.3

2. E.g. steel, cast iron, copper, Al, glass fiber



Permanent magnet generator
VESTAS report, papers

Literature/ company report

- Upscaling
- Replace and new materials

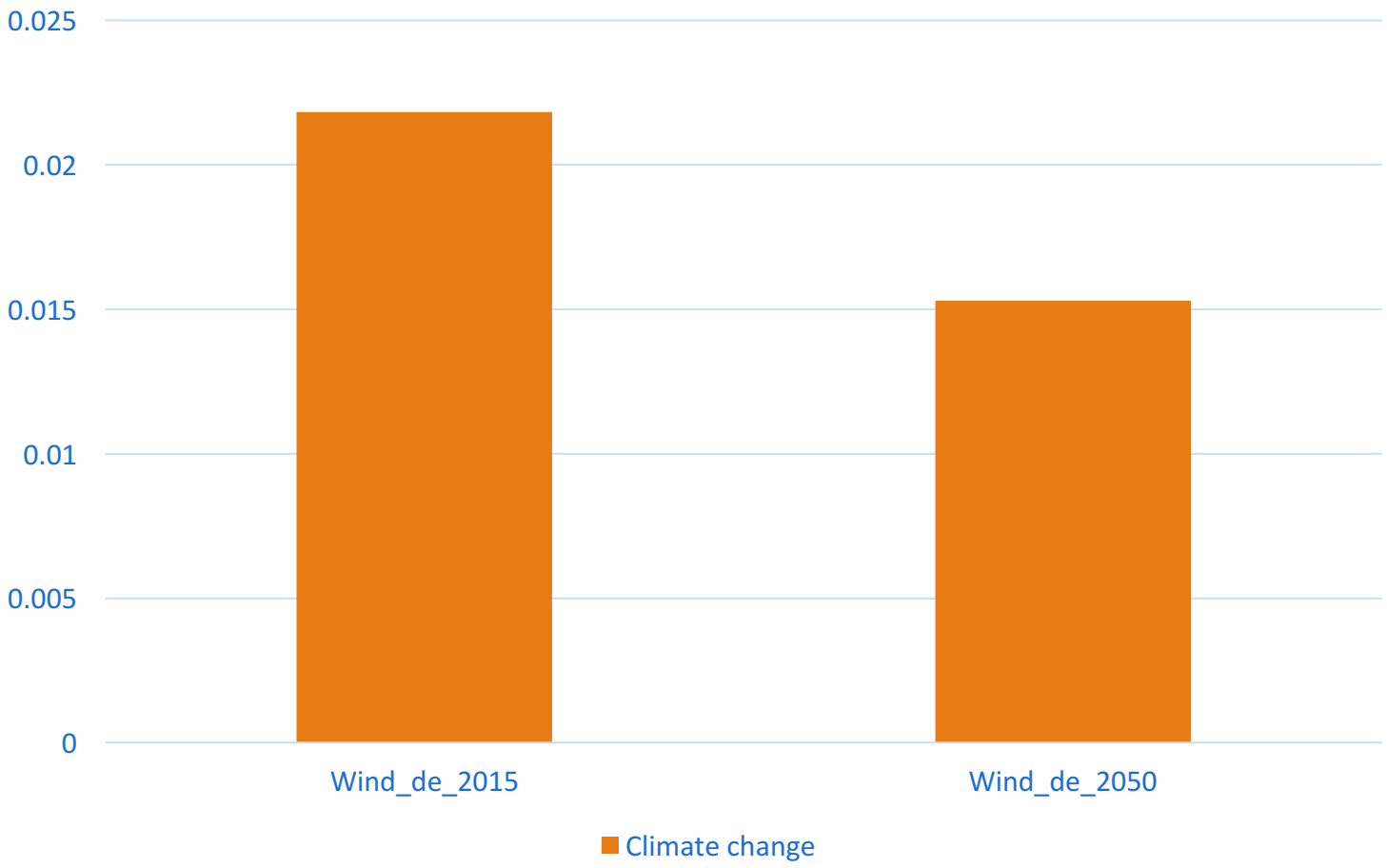
- Adapt the literature inputs to kg/MW
- Economic and availability issues

Inventory for future technologies

2. Update reference LCIs, e.g. wind-onshore

	ECOINVENT	2050	
		Conventional	Next generation
		80%	20%
Process's name	wind turbine construction, 2MW, onshore		
Life-time (year)	20	20	20
Capacity (MW)	2	32	32
Main materials input			
Steel (kg/MW)	1.35E+04	2.40E+04	2.40E+04
Cast iron (kg/MW)	1.04E+04	1.80E+04	1.80E+04
Copper (kg/MW)	1.41E+03	5.00E+01	5.00E+01
Aluminum (kg/MW)	2.69E+02	7.27E+02	7.27E+02
Glass fiber reinforced plastic (kg/MW)	7.10E+03	7.54E+02	7.54E+02
Concrete (m^3/MW)	1.75E+02	1.58E+02	1.58E+02
Carbon fiber (kg/MW)		5.00E+03	5.00E+03
Neodymium oxide (kg/MW)			5.0E+01

Comparative results e.g. climate change for wind power - onshore



Life cycle inventories (Utopia)

	Data	Data sources
Foreground	Overall basic data (reference LCI)	Eco invent Literature review
	Updating: Materials consumption for promising technologies, i.e. wind, solar	Literature review Company reports Assumptions
	Updating: Quantity of energy services Generation capacity and life time Fuel consumption Generation efficiencies, etc.	ESMs (Input)
Background	Overall basic data	Eco invent database
	Updating: Energy mix, e.g. electricity mix, heat mix. E-mobility data	ESMs (Output)
	Updating: Energy mix (rest of the studied geographical and technological scope) Technological improvement related to material production, infrastructure, etc.	Other ESMs Literature review Assumptions

1. Development of reference LCIs

Technologies	Sources
Wind onshore	Ecoinvent 3.3
Wind offshore	Ecoinvent 3.3
Photovoltaic	Ecoinvent 3.3
Concentrated solar plant	Literature
Biomass	Literature
Geothermal	Ecoinvent 3.3
Hydro power	Ecoinvent 3.3
Carbon capture and storage	Literature
Other conventional technologies	Ecoinvent 3.3

Thanks for your attention

Data gathering and modeling contacts:

- maryegli.fuss@kit.edu
- lei.xu@kit.edu