Ökobilanz-Werkstatt 2010

Lebenszyklusanalyse solarer Energieerzeugungstechnologien im südlichen Afrika

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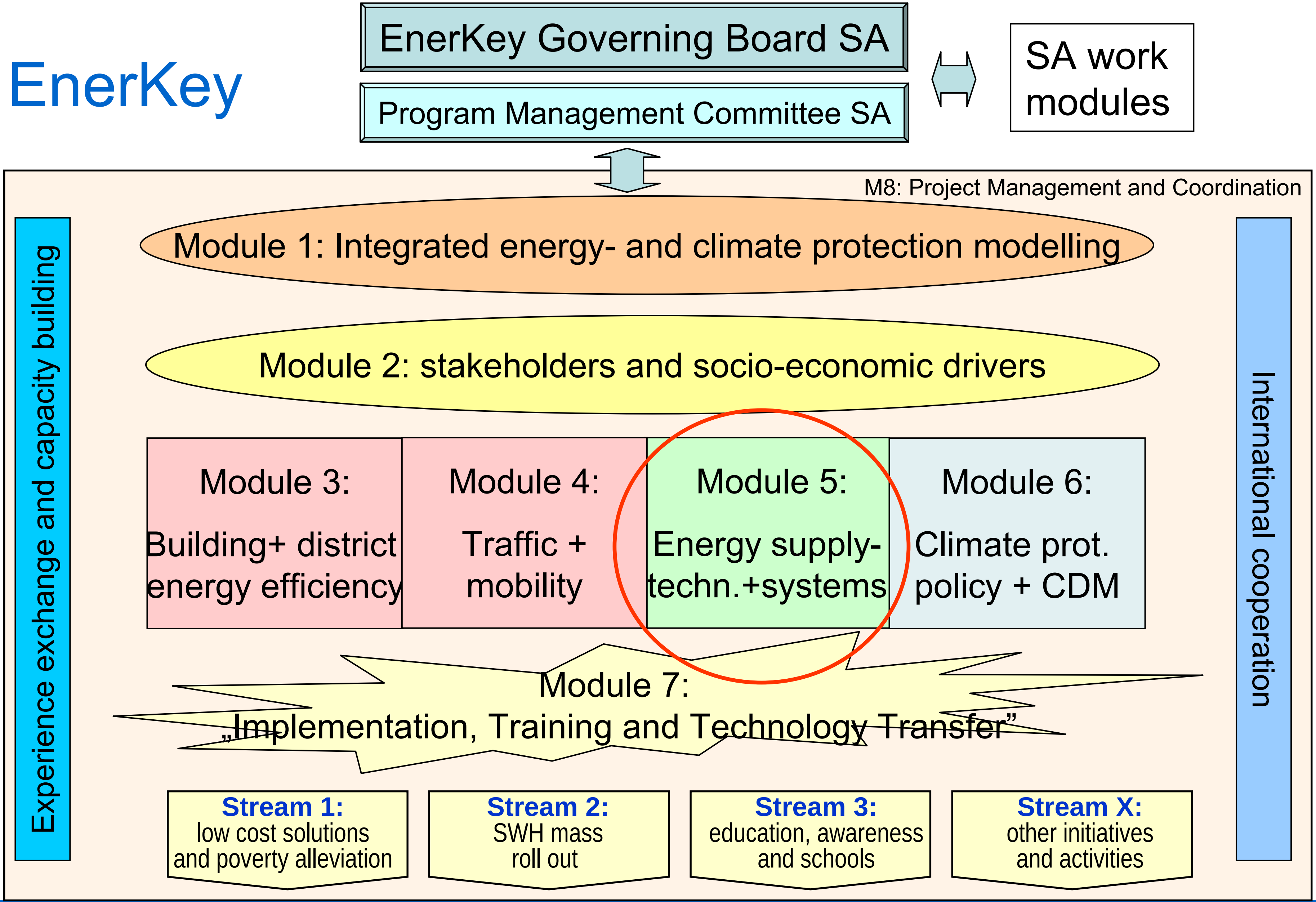
Agenda

- Aim and Scope
- Technology Overview / Reference Power Plants
- Methodology
- Parameterisation
- Preliminary Results

EnerKey


EnerKey Governing Board SA
Program Management Committee SA
SA work modules
M8: Project Management and Coordination
Experience exchange and capacity building
Module 1: Integrated energy- and climate protection modelling
Module 2: stakeholders and socio-economic drivers
Module 3: Building+ district energy efficiency
Module 4: Traffic + mobility
Module 5: Energy supply- techn.+systems
Module 6: Climate prot. policy + CDM
Module 7: „Implementation, Training and Technology Transfer"
Stream 1: low cost solutions and poverty alleviation
Stream 2: SWH mass roll out
Stream 3: education, awareness and schools
Stream X: other initiatives and activities
International cooperation

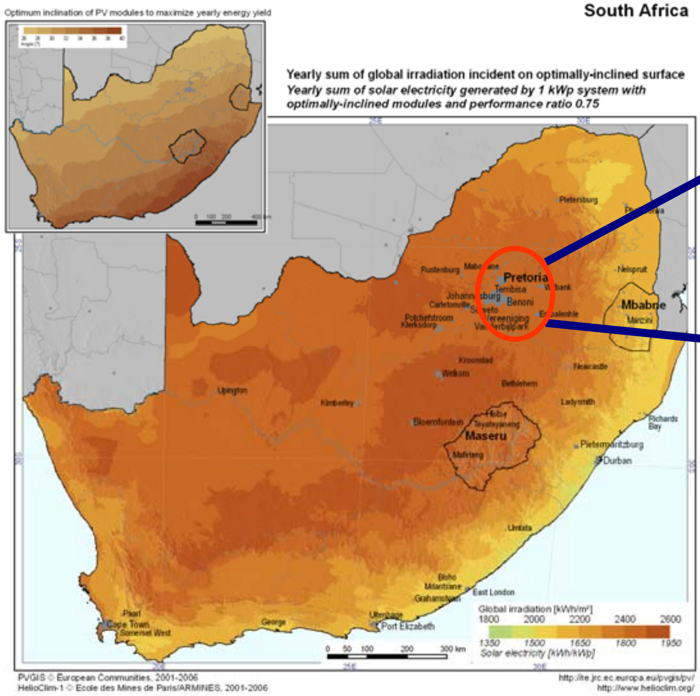
Context

Statistics 2007:

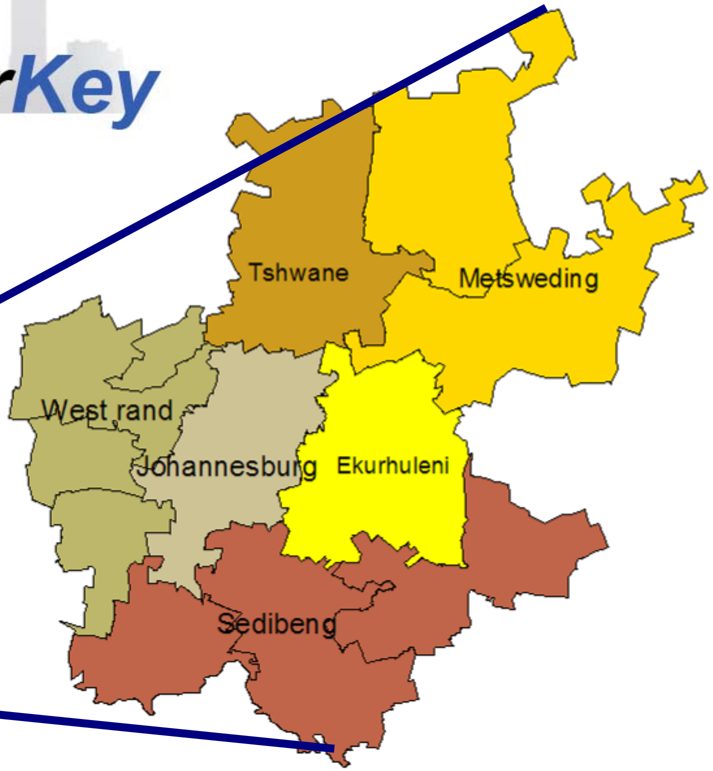
Population: 10,4 million / 21.6 % of SA

GDP: 682.8 bZAR(2007) / 34% of SA

StatsSA CS2007, StatsSA P0441 2007



EnerKey



- High solar radiation potential
- Assessment of solar generating technologies

Scope

- Characterisation and Analysis of solar electricity generation
- Technology perspectives under different climatic and economic conditions
- Performance Ratio Solar Power
- Comparison with conventional electricity generation techniques
- Assessment of future technology development

Modellstruktur P-LCA

Interpretation of results

Expansion to Parametrised LCA (P-LCA)

- Selection Input Parameter
- Selection System Parameter
- Defintion Scaling Functions

➔ Modification of assumptions and technical settings of the same product system

LCA Reference Modell

➔ Life Cycle Impact Assessment (LCIA)

➔ Life Cycle Costing (LCC)

Calculation Power Plant Design

•Solar Field
•Storage Option
•Power Block (Cooling method)
} Configuration

➔ Design Point under thermodyn. constraints

Life Cycle Inventory

•Construction
•O&M
•Dismantling

➔ Material, Energy, Area

Technology overview

Stage of development	Large scale production
Field of application	Grid connected power plant
Range of capacity	30-250 MW
Parameter Working Fluid	390-415°C (100bar)
Storage possibility	yes

Close to large scale
Grid connected power plant
5-250 MW
270-450°C (100bar)
yes

Close to large scale
Decentralised systems
0,01-0,03 MW
800-900°C
no

Commercial pilot projects
Grid connected power plant
10-100 MW
550-1050°C (15 bar)
yes

Large scale production
Grid connected power plant
0,01-60 MW
-
Battery

Identification reference power plants

• Parabolic Trough	50MW	7.5h	Andasol 1-3
• Solar Tower	20MW	7.5h	
• Fresnel	50MW	7.5h	
• Parabolic Dish	0.01MW	0h	
• PV (Crystalline silicon)	50MW	0h	
• PV (Thin film)	50MW	0h	

Modellstruktur P-LCA

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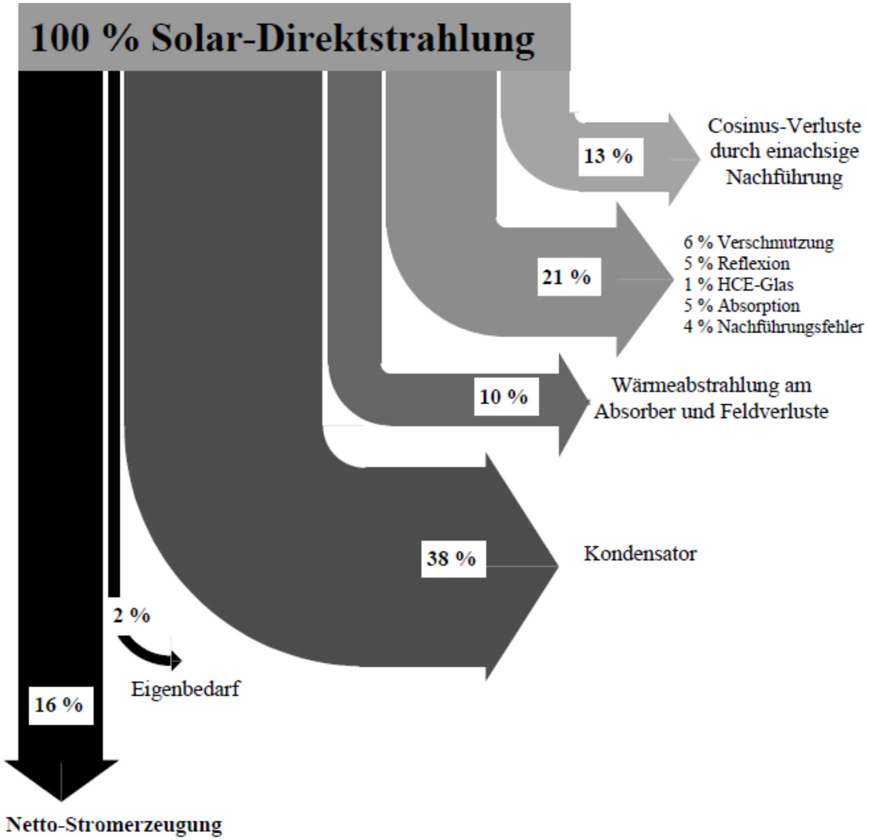
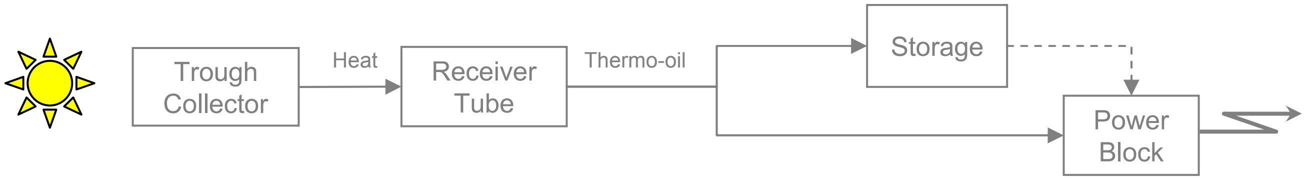
Calculation Power Plant Design

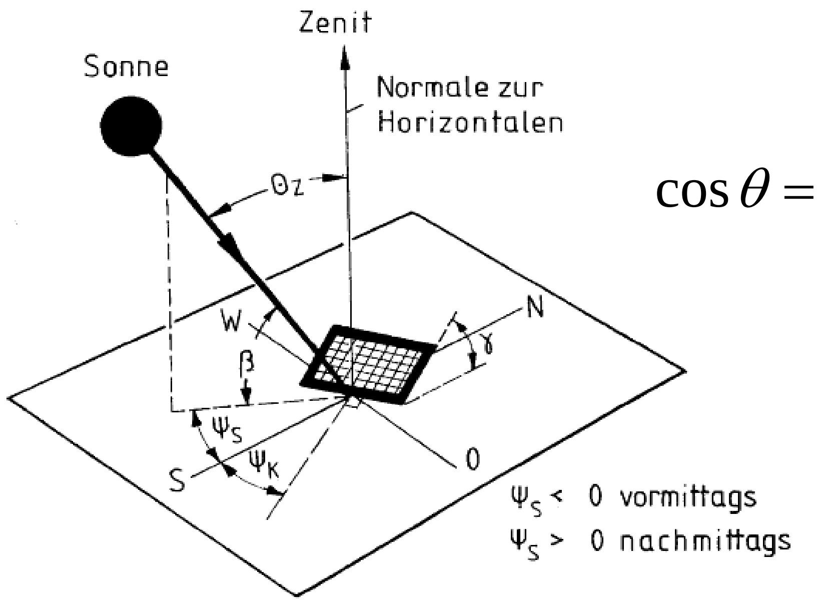


Quelle: Trieb, SOKRATES-Projekt, Technologiedatenbank

- Starting point: The sun
- Determination of loss factors that affect the emitted solar radiation
  1) Geometrical losses
  2) Shading
  3) Optical losses
  4) End of row losses
  5) Convection losses
  6) Thermal radiation losses
  7) Wind losses



Calculation Power Plant Design



Quelle:Drück, Müller-Steinhagen, Manuskript Solartechnik 1

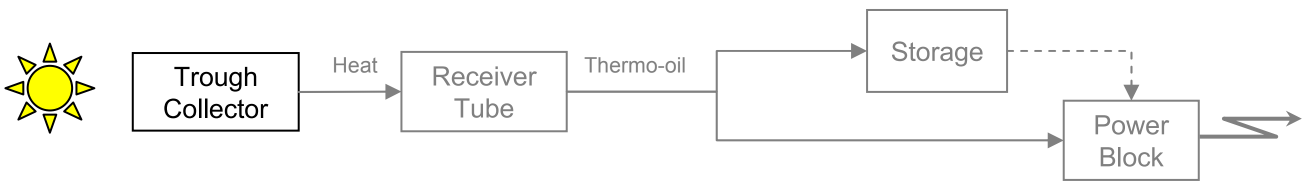
- Orientation Trough Collector

$$\cos\theta = \cos\beta \cdot \cos\theta_Z + \sin\beta \cdot \sin\theta_Z \cdot \cos(\gamma_C - \gamma_S)$$

- Inclination angle onto the aperture
- Optimal orientation of the collector field N-S

➔ Calculation of loss factors

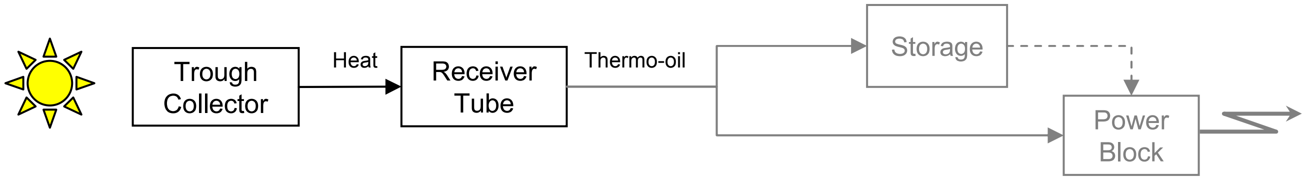
$$\cos\theta = \cos\beta \cdot \cos\theta_Z + \sin\beta \cdot \sin\theta_Z \cdot \sin\left|\gamma_S\right|$$



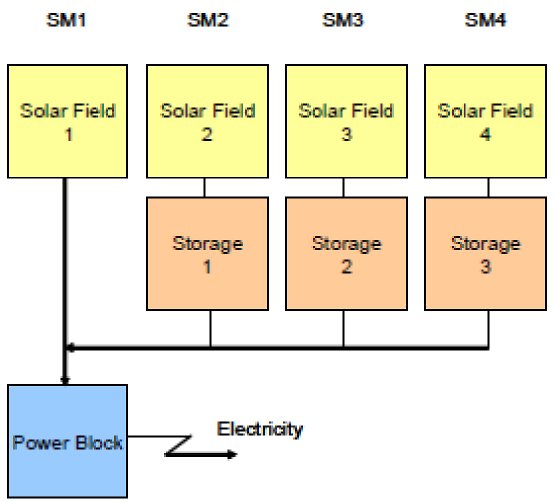
Calculation Power Plant Design

- Collector and Receiver tube loss factors:
  1) Convection
     e.g.: (contamination of mirrors)
     transmission
     reflection
  2) Thermal Radiation
  3) Wind Speed
     <15 m/s no losses
     <45 m/s linear increase
     >45 m/s shutdown

$$\dot{Q}_{SF} = IDR \cdot A_{Kol} \cdot \Psi \cdot \left[\delta \cdot \rho \cdot \tau_S^2 \cdot \gamma \cdot \tau_H \cdot \alpha - \frac{U \cdot \pi}{IDR \cdot C} \cdot (T - T_U) - \frac{\pi \cdot \sigma \cdot \varepsilon}{IDR \cdot C} \cdot (T^4 - T_H^4) \right]$$



Calculation Power Plant Design

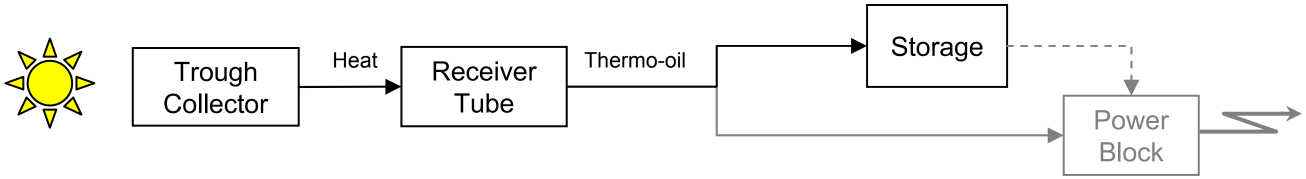


Quelle: Trieb, DLR; Characterisation of Solar Electricity Import Corridors from MENA to Europe

- Consideration of an on-site storage by using the Solar Multiple concept (DLR)
- Solar Multiple Configuration defines storage capacity (0h-18h)

➔ Availability

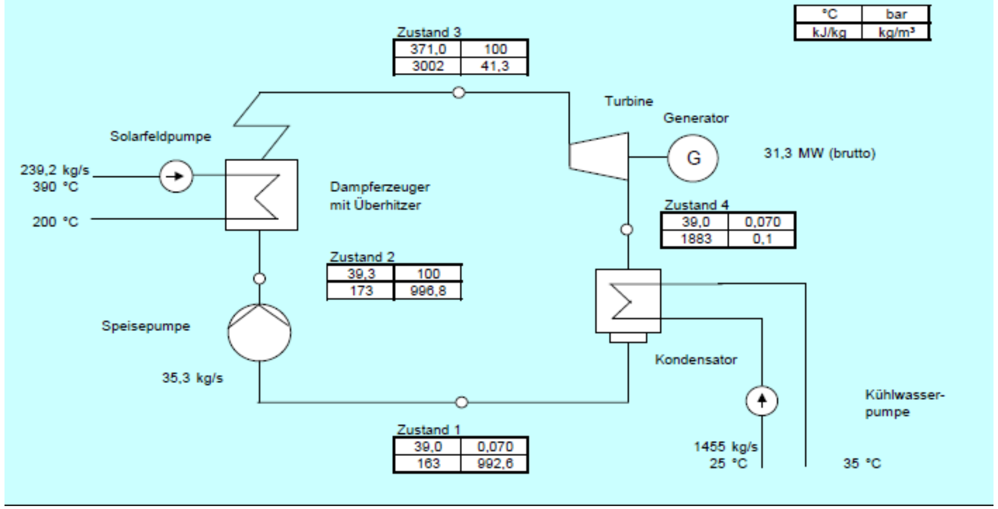
$$Flh = (2.5717 \cdot DNI + 694) \cdot (-0.0371 \cdot SM^2 + 0.4171 \cdot SM - 0.0744)$$



Calculation Power Plant Design

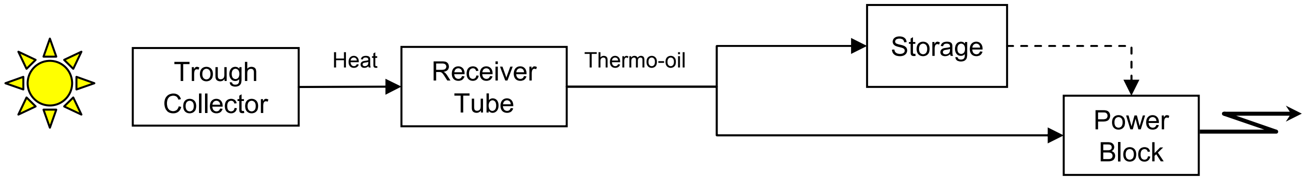
- Power Block Modell: Clausius-Rankine process
- Input parameters: heat solar field, process steam parameters (T, p), efficiency of components
- Optional possibilities to enlarge the system (co-firing, cooling, desalination)

➔ Parasitics, Power into grid, Efficiency



$$dU = \delta Q + \delta W$$

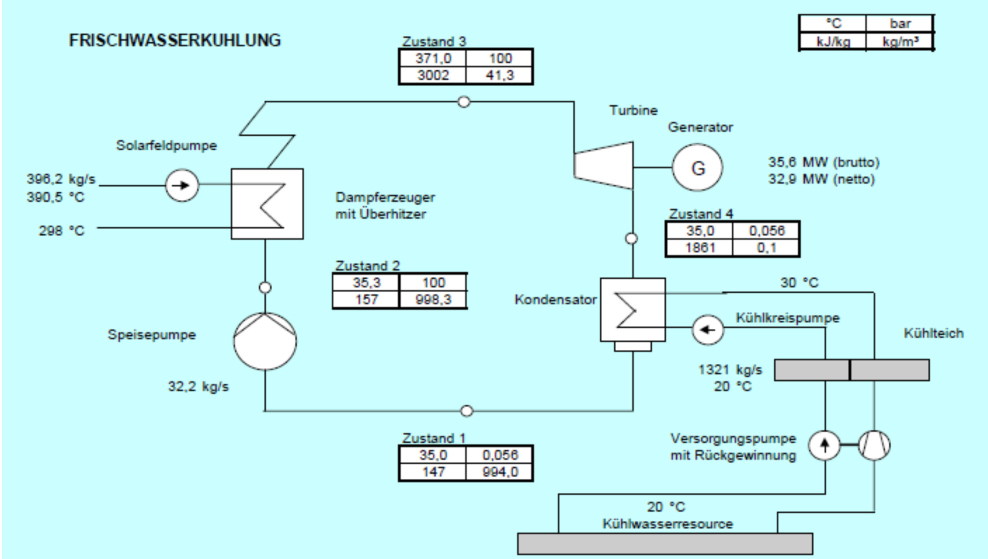
$$\eta_{netto} = \frac{P_{th} \cdot \eta_G - P_{Parasitics}}{\dot{Q}_{SF}}$$



Calculation Power Plant Design

- Power Block Modell with wet cooling of the condenser
- Distance and sea level of cooling resource site
- Process parameters of cooling fluid (w, T)

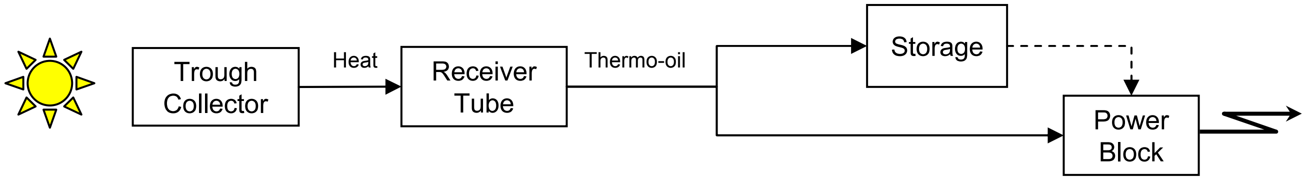
➔ Way of cooling affects the efficiency and electricity output



$$dU = \delta Q + \delta W$$

$$P_{KP} = \dot{m}_W \cdot \left[\Delta z \cdot g + \frac{w^2}{2} + \frac{\Delta p}{\rho} + \frac{\Delta p_V}{\rho} \right] \cdot \frac{1}{\eta_{KP}}$$

$$\eta_{netto} = \frac{P_{th} \cdot \eta_G - P_{Parasitics}}{\dot{Q}_{SF}}$$



Modellstruktur P-LCA

LCA Reference Model

➔ Life Cycle Impact Assessment (LCIA)

➔ Life Cycle Costing (LCC)

Calculation Power Plant Design

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•Storage Option
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➔ Design Point under thermodyn. constraints

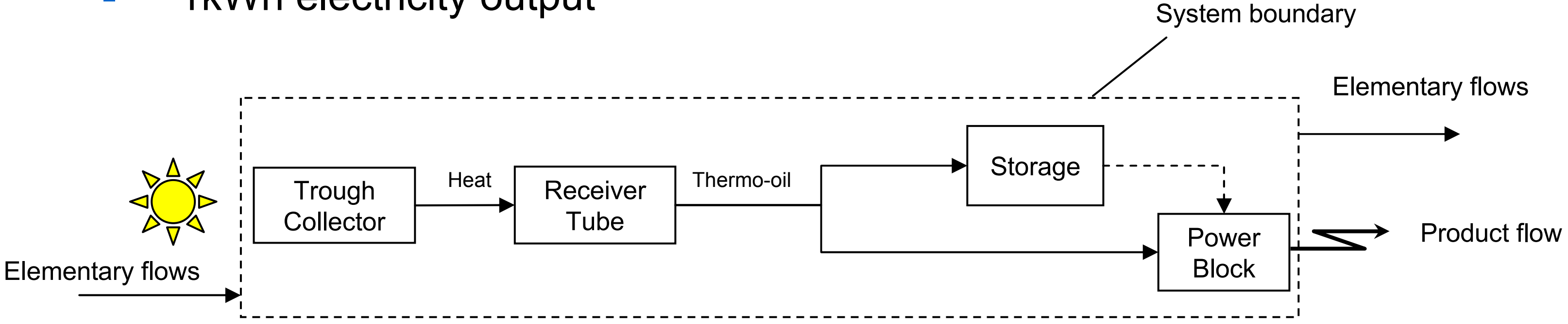
Life Cycle Inventory

•Construction
•O&M
•Dismantling

➔ Material, Energy, Area

Life Cycle Inventory

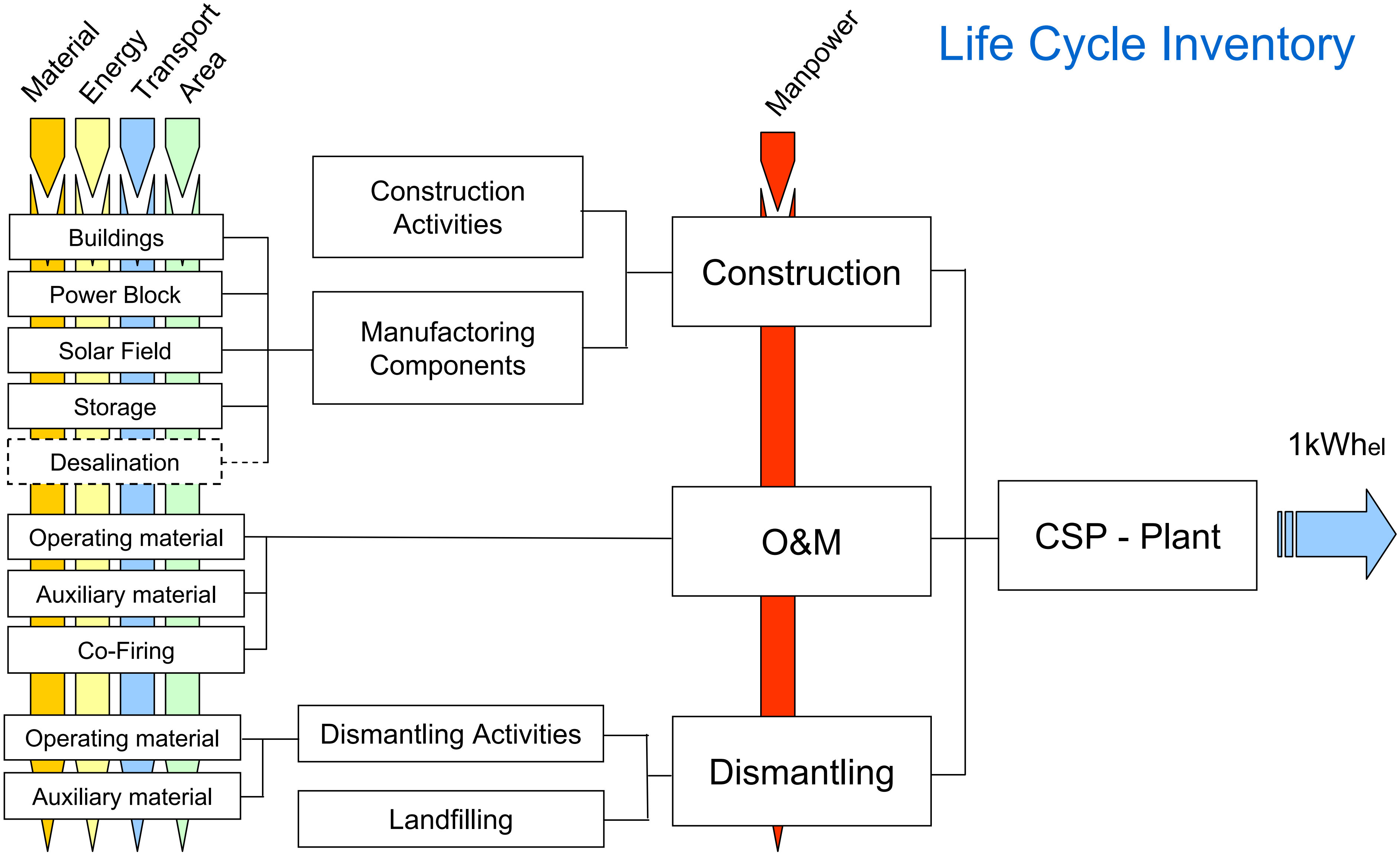
- Functional unit of the life cycle
  - 1kWh electricity output



- Life cycle inventory data
  - Literature based research (Technology reports, papers informations of AndaSol 1)
  - Conference presentations, personal contact AndaSol 3 companies

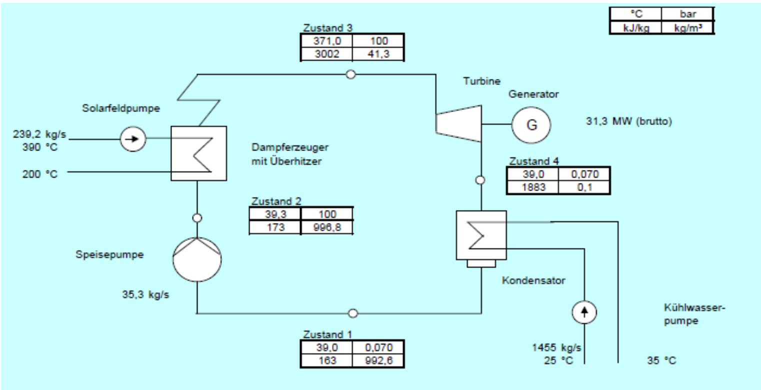
➔ Materials, Energy carriers, area requirements, transport, disposal services

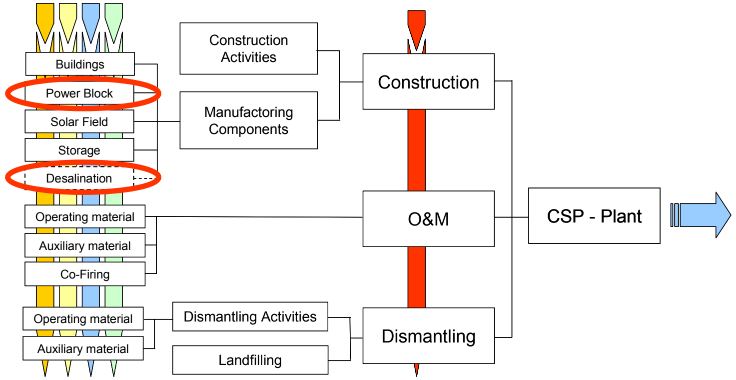
Life Cycle Inventory

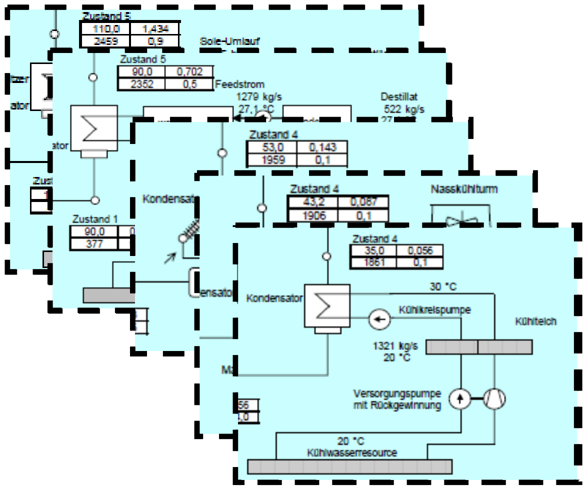


Nexus Design Calculation - Life Cycle Inventory

- Reference system can be extended in various ways







- Condenser cooling (dry, hybrid, wet)
- Desalination
- Co-Firing

Modellstruktur P-LCA

Expansion to Parametrised LCA (P-LCA)

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Life Cycle Inventory

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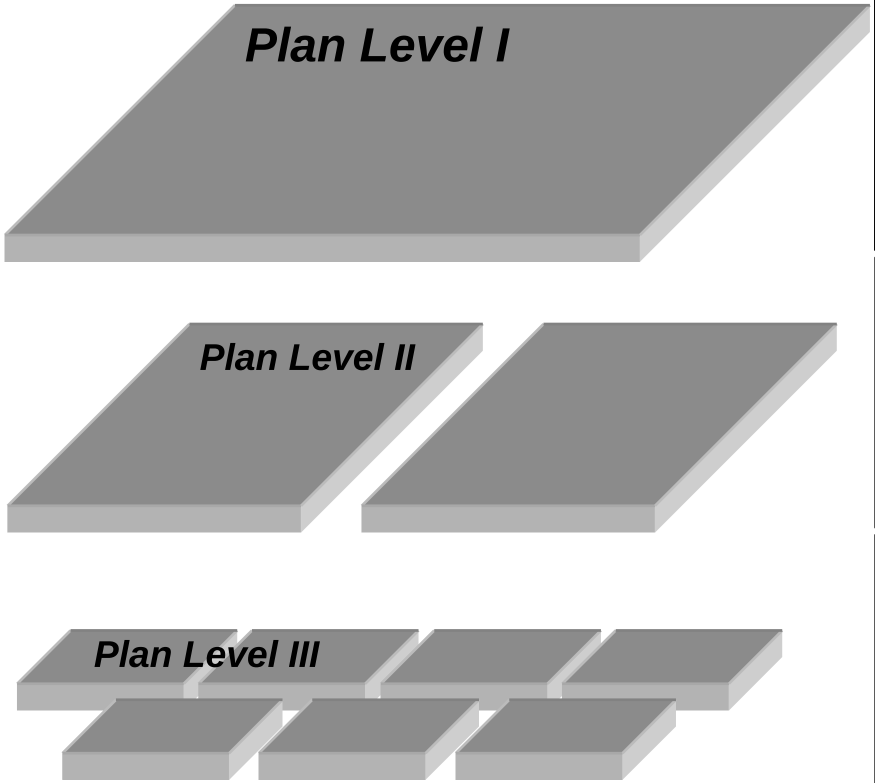
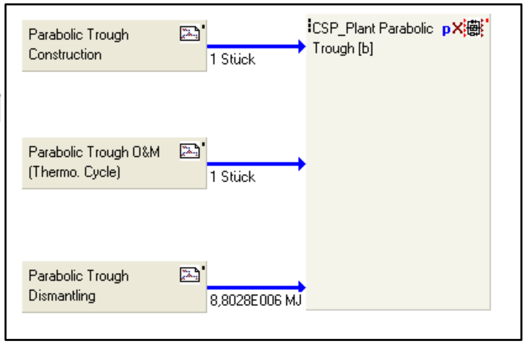
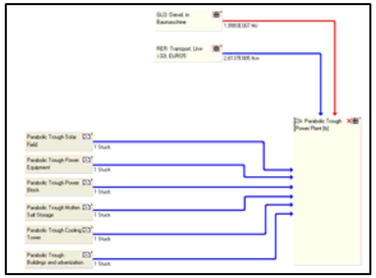
•Dismantling

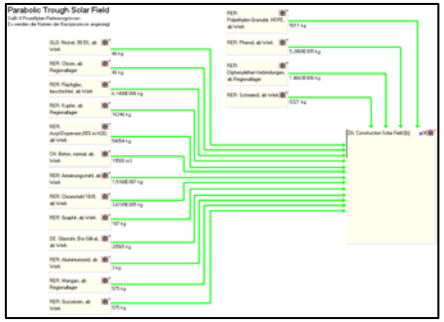
➔ Material, Energy, Area

LCA Structure Plan Nesting (Reference Modell)









- Life Cycle
- Costruction & Assembly
- Materials

Life Cycle Impact Assessment (reference model)

Type of Power plant	Parabolic Trough
Latitude	34°
Time of year	Summer (01.07)
DNI	800 W/m²
Solar Field: Collector Area	510120 m²
Average wind speed	10 m/s
Storage capacity	7.5 h/d
Full load hours	5015 h/d
Condenser	Wet cooling
Distance to water ressource	500 m

Darmstadt (49° 52′ N, 8° 39′ O , 200 W/m²)

$$\eta_{netto} = \frac{P_{th} \cdot \eta_G - P_{Parasitics}}{\dot{Q}_{SF}} = 0.1684$$

$$P_{netto} = 42.1698 MW$$

$$\eta_{netto} = \frac{P_{th} \cdot \eta_G - P_{Parasitics}}{\dot{Q}_{SF}} = 0.1095$$

$$P_{netto} = 7.2213 MW$$

Parameterisation

- Classification and use

Input parameters

a) Variable	b) Constant
Latitude	Heat capacity
DNI	Loss coefficients
Time of year	Daytime
Dimensions Collector	
Aperture Area	
Temperature	
Wind speed	
Temperature (HTF,Steam)	
…	

System parameters

- Heat Solar Field

$$\dot{Q}_{SF} = IDR \cdot A_{Kol} \cdot \Psi \cdot [\Sigma \xi]$$

- Heat Condenser

$$\dot{Q}_{Kond} = \dot{m}_D \cdot (h_4 - h_1)$$

- Pumps

$$\dot{Q}_{Pump} = \dot{m}_{fluid} \cdot c_{p\_fluid} \cdot \Delta T$$

Scaling functions

- Materials Solar Field

$$f_{SF} = \frac{\dot{Q}_{SF\_neu}}{\dot{Q}_{SF\_reference}}$$

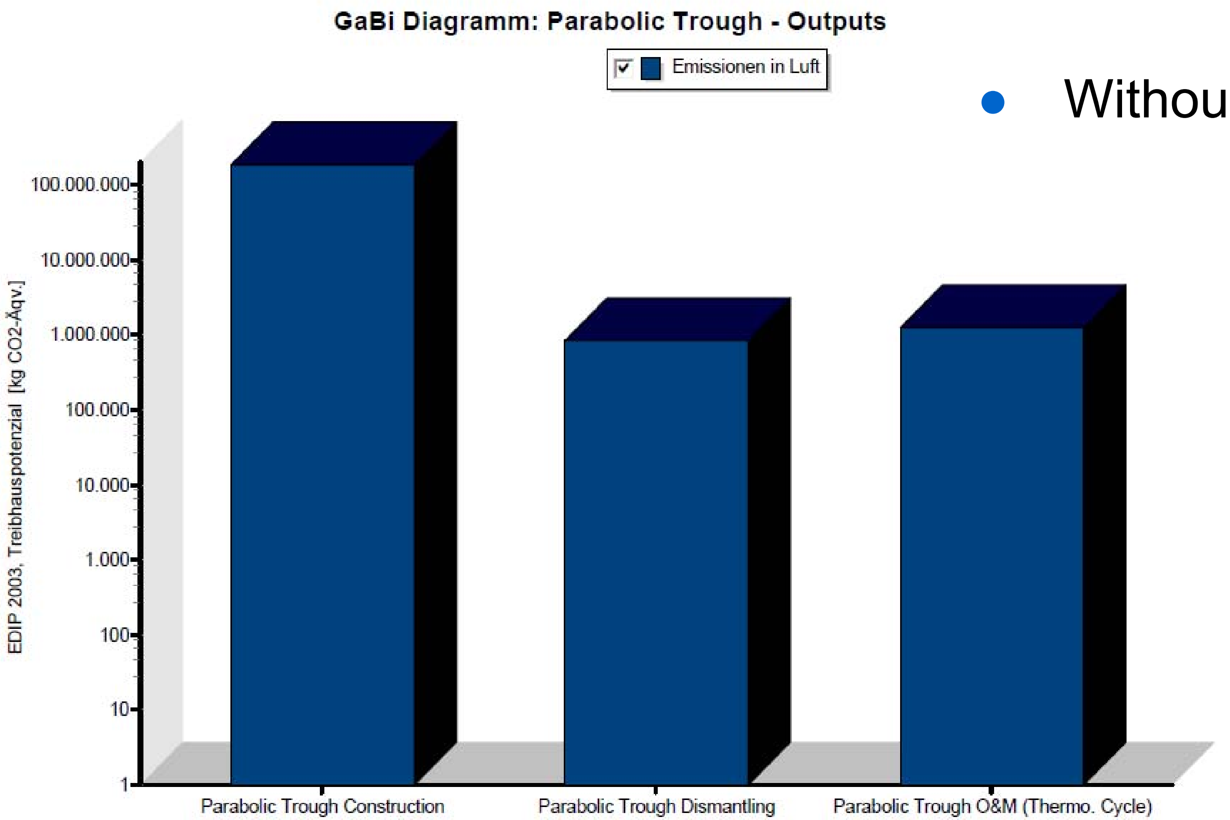
- Materials Cooling Tower

$$f_{Kond\_Cool} = \sqrt[\frac{2}{3}]{\frac{\dot{Q}_{Kond\_neu}}{\dot{Q}_{Kond\_reference}}}$$

- Materials Piping

$$f_{Pump} = \sqrt[2]{\frac{\dot{Q}_{Pump\_neu}}{\dot{Q}_{Pump\_reference}}}$$

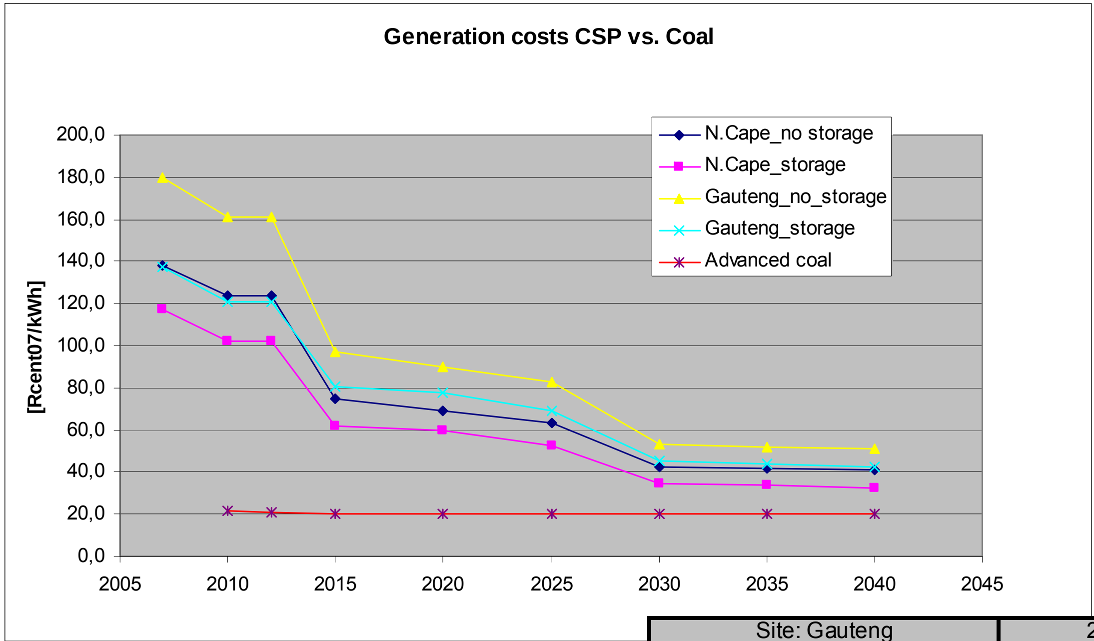
Preliminary results (reference model)



- Without Co-firing

	Construction	Dismantling	O&M
GHG_Emissions [g_CO_{2_eq}/kWh]	29,223	0,128	0,195 (~+160)

Preliminary results



- GHG Emissions 184 g CO_{2_eq}/kWh (Lechón)
- Technology learning rates (PR):
  - Solar Field: 90%
  - Power Block: 98%
  - Storage: 92%
- Economies of scale (PR): 80%

Site: Gauteng		2010		2020		2040	
DNI	2200 kWh/m²/a	Invest. [R/kW]	LEC [Rc/kWh]	Invest. [R/kW]	LEC [Rc/kWh]	Invest. [R/kW]	LEC [Rc/kWh]
NO STORAGE:	SM1	26.255	161,4	16.517	89,9	10.101	50,9
STORAGE:	SM2 - SM4	45.012	121,0	48.101	77,7	26.316	42,5
Site: Northern Cape		2010		2020		2040	
DNI	2800 kWh/m²/a	Invest. [R/kW]	LEC [Rc/kWh]	Invest. [R/kW]	LEC [Rc/kWh]	Invest. [R/kW]	LEC [Rc/kWh]
NO STORAGE:	SM1	26.255	123,5	16.517	69,2	10.101	40,9
STORAGE:	SM2 - SM4	45.012	102,3	48.101	59,4	26.316	32,6
Site: South Africa		2010		2020		2040	
		Invest. [R/kW]	LEC [Rc/kWh]	Invest. [R/kW]	LEC [Rc/kWh]	Invest. [R/kW]	LEC [Rc/kWh]
Advanced Coal Power Plant		15.278	21,7	13.636	20,0	13.636	19,9

Open Questions

- Nexus solar technologies & solar potential with GIS?
- Modelling of prototypes: Life cycle inventory data?
- Methodology of Life Cycle Costing?
  1. Manpower
  2. Material Costs

➔ Identification of power plant sites

Siting

Vielen Dank für Ihre Aufmerksamkeit!