Spatially and Temporally Resolved Modeling of Parabolic Trough Plants and Adaptation of greenius

Marc Röger, Eckhard Lüpfert, Simon Caron, Simon Dieckmann

greenius User Day 2015

Cologne, 30 Sep 2015

DLR

Introduction to PARESO Project – greenius Adaptation

Goal of PARESO project (WP 6):

- Modeling of parabolic trough field with **damaged receivers**
- Investigate repair / replacement strategies

Special requirements for greenius

- **Spatially inhomogeneous** collector loops
- **Temporal variation** of optical and thermal receiver quality
- **Additional investments for repair** at specific points in time t+1 possible
- Calculation of **each** operating year

greenius
THE GREEN ENERGY SYSTEM ANALYSIS TOOL

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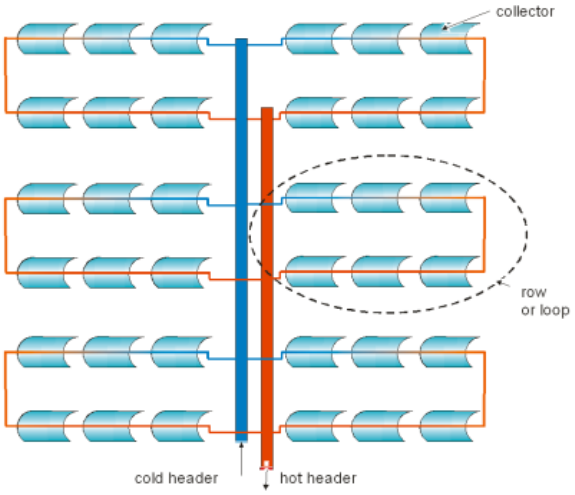
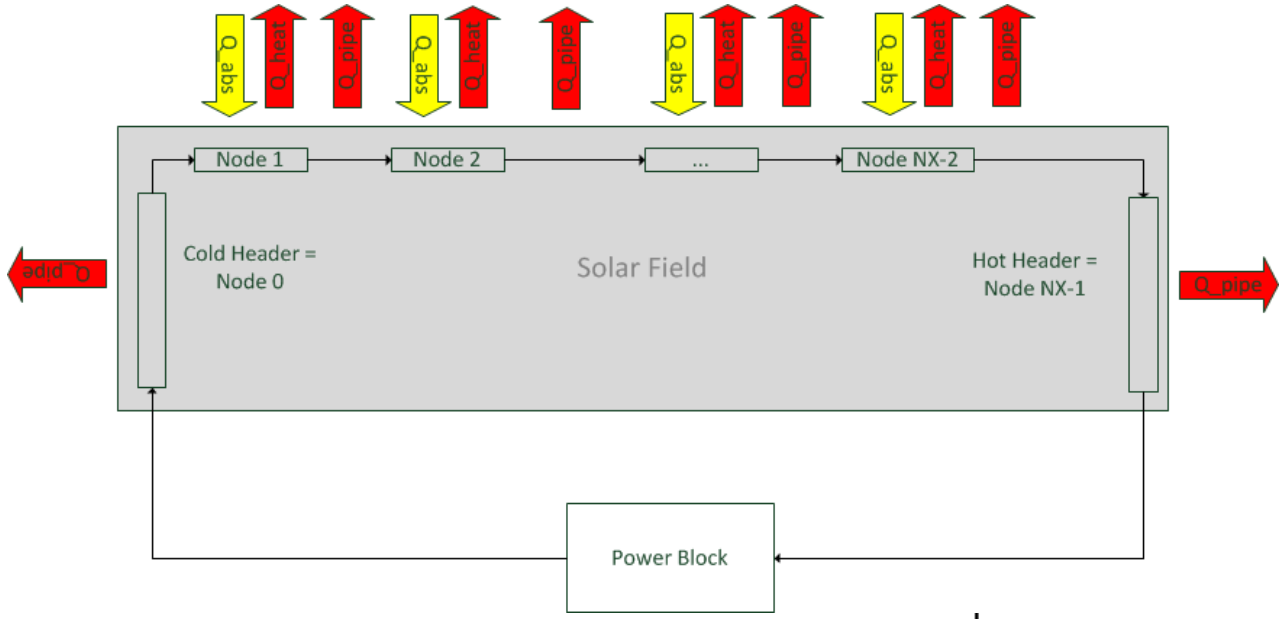
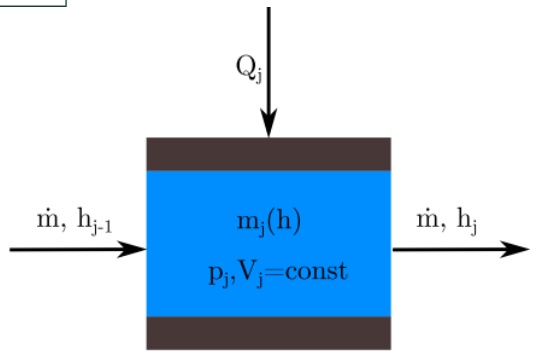
Loop Divided into Nodes





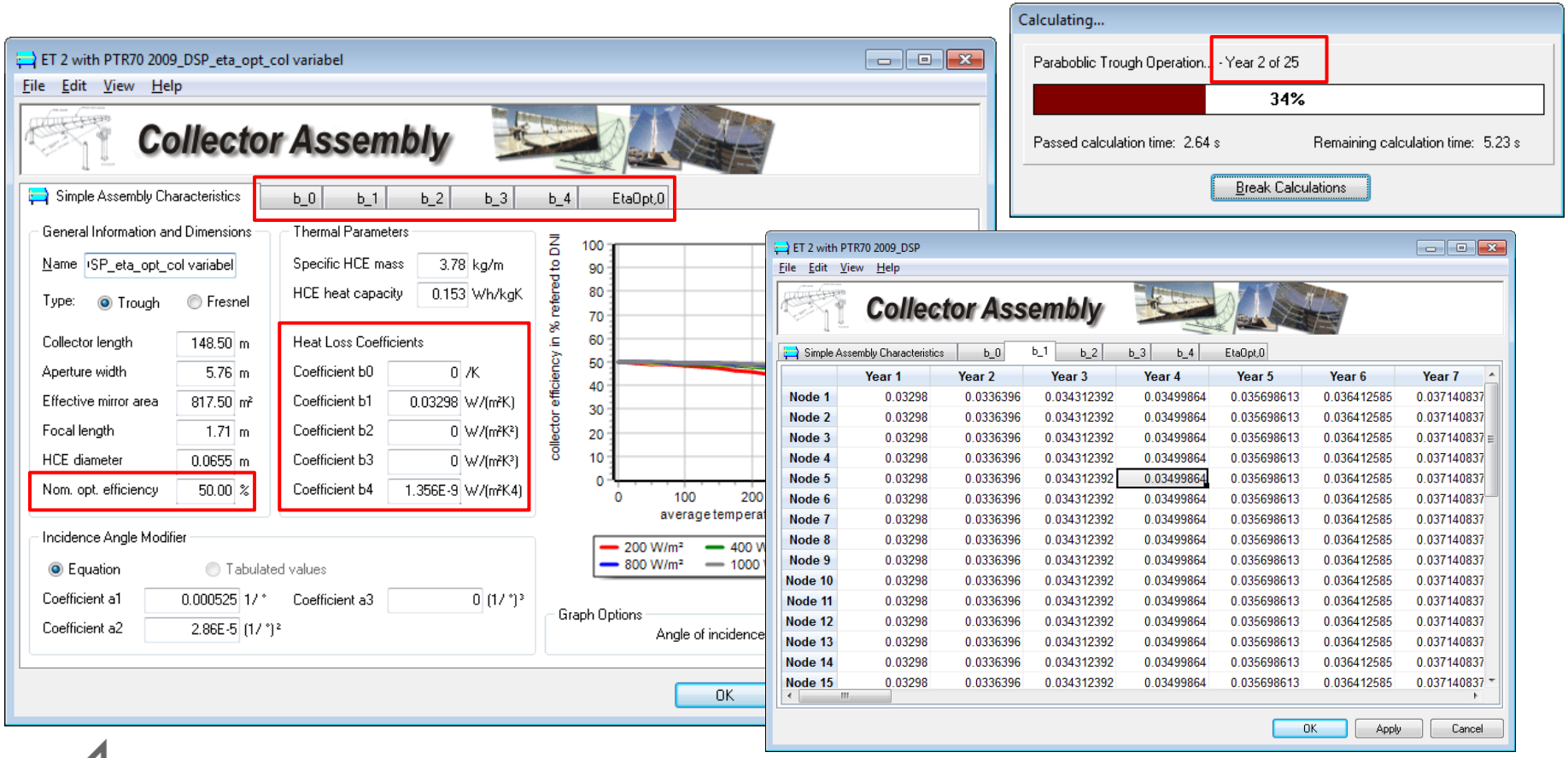
$$Q_j^k = \underbrace{\dot{m}^k \left(h_j^k - h_{j-1}^k\right) \Delta t}_{\text{Konvektiver Transport}} + \underbrace{m_j^k h_j^k - m_j^{k-1} h_j^{k-1}}_{\text{Aufheizung Massendifferenz}} + \underbrace{m_w c_{p,w} \left(T_j^k - T_j^{k-1}\right)}_{\text{Aufheizung Rohrwand}}$$



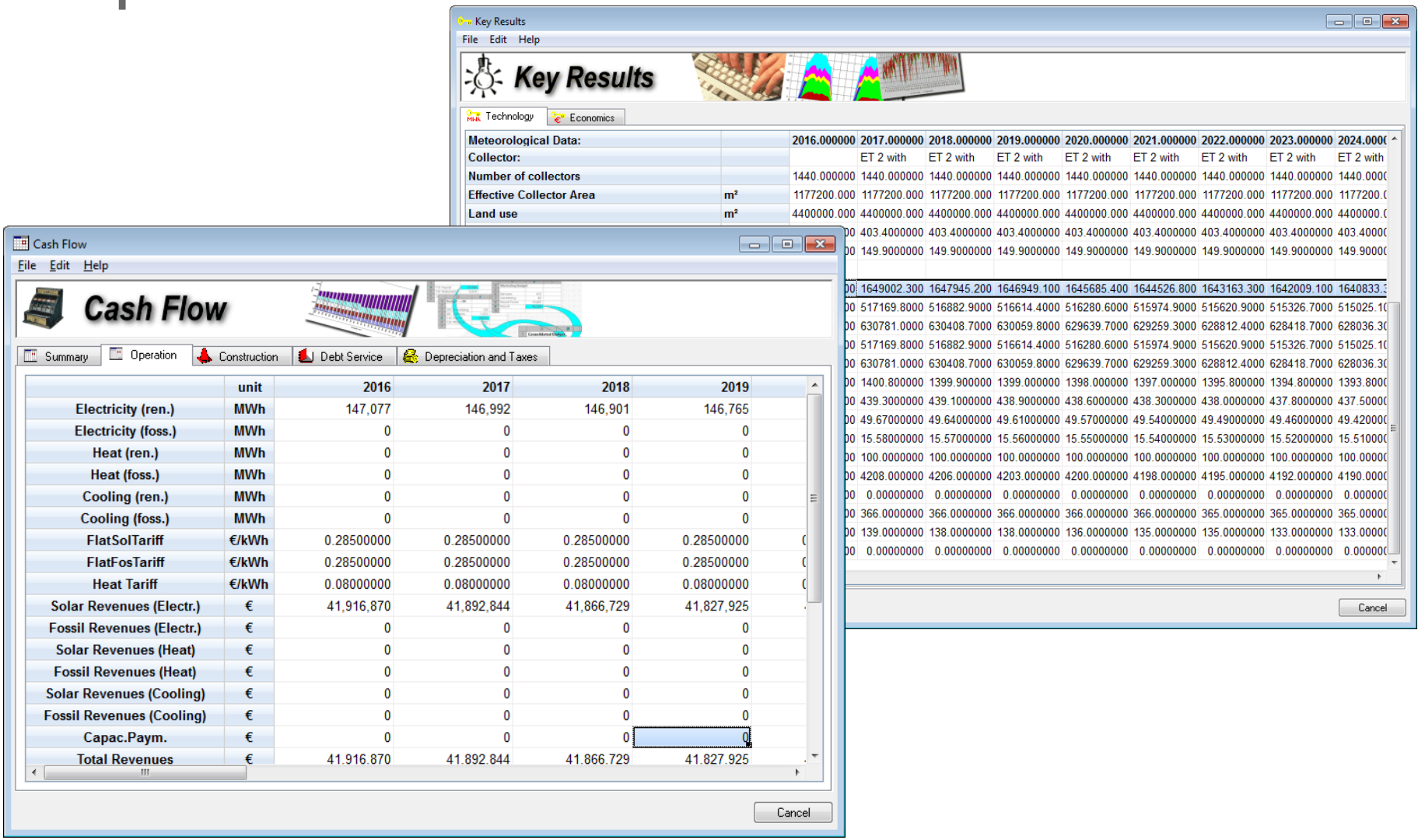
→ Adaptation of enhanced model (DSG) for single phase fluids

Definition of Heat Loss Coefficients

$$\eta_{collector} = K \cdot \eta_{opt,0} \cdot \eta_{cleanliness} - \left(K \cdot b_0 \cdot \Delta T + \frac{b_1 \cdot \Delta T + b_2 \cdot \Delta T^2 + b_3 \cdot \Delta T^3 + b_4 \cdot \Delta T^4}{DNI} \right)$$



Output of Results



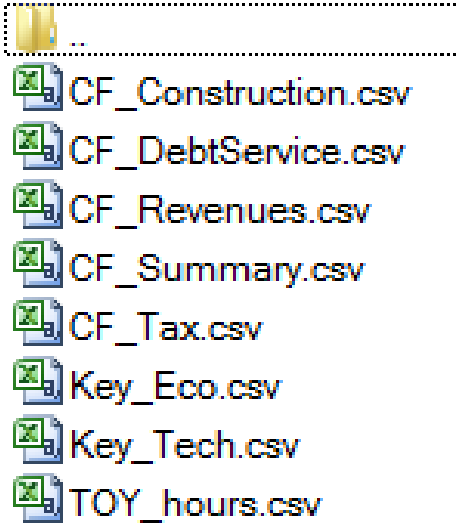
Automatisation of Greenius

- High Computational Effort
  - Spatial resolution
  - Calculation of each operational year
  - Parameter Variations
- Use console start of **greenius**

```
cd d:\Programme\Greenius
greenius.exe d:\projectFile.gpj d:\outputPath\
```

- Modification of project files (*.gpj / *.gpa)
- Start **greenius** simulations
- Analyse results / plot data

Matlab



Console Start

..\Greenius\data\project.gpj

..\Greenius\data\Technology\Troughs\
Collector\collectorFile.gpa

%CMPDATADIR = Default Component Directory

PRJ01_Maan150MW_360_Loops.gpj

```
Technology	2
Project_name	PARESO-PRJ01
Created	736172.7745
Last_saved	736172.7745
Nation	%CMPDATADIR\Jordan_Marc.gpa
Location	%CMPDATADIR\Location_Jordan - Maan.gpa
Loadcurve
Meteo	%CMPDATADIR\Jordanien - Maan_enerMENA2013.gpa
Costs	%CMPDATADIR\AddOMCosts_PARESO-PRJ01.gpa
Timing
Financing	%CMPDATADIR\Test_Marc.gpa
Troughsam	%CMPDATADIR\ET2 with PTR70 2009 - DSP_eta_opt_PARESO-PRJ01.gpa
Troughfield	%CMPDATADIR\Test-DetailedSinglePhase_Jordan_Maan_150MW_Marc_360Loops.gpa
Boiler	%CMPDATADIR\Kein Kessel.gpa
Powerblock	%CMPDATADIR\150MW_ACC_2014.gpa
Storage	%CMPDATADIR\Storage_Jordan_Maan_150MW_Marc.gpa
```

PRJ01_Maan150MW_360_Loops.gpj | ET2 with PTR70 2009 - DSP_firstHalfHCEbroken.gpa

D:\projects\greenius-pareso\data\PRJ01_Maan150MW_360_Loops.gpj

```
name	ET 2 wit
source	NREL 2009
contact	greenius Team
focal_length	1.71
col_length	148.5
aperture_width	5.76
Aeff	817.5
optical_efficiency	0.75
colector_type	0
ta1	0.000525
ta2	2.86E-5
ta3	0
b0	0
b1	0.03298
b2	0
b3	0
b4	1.356E-9
HCE_diameter	0.0655
specific_HCE_mass	3.78
specific_HCE_capacity	0.153
IAMfit	0
b_0Matrix
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

b_1Matrix
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03
0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03
0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03
0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03
0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03
0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03298 0.03

b_2Matrix
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
```

Technical Background of Receiver Replacement Study, Methodology and Results

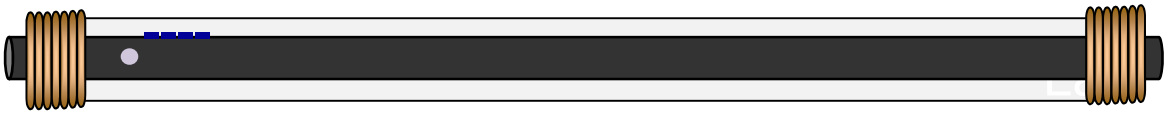
Speaker: Marc Röger

marc.roeger@dlr.de

Overview

1. **MOTIVATION** of Study
2. **REFERENCE** Parabolic Trough Plant
3. **SCENARIOS** for Receiver Performance Loss
4. **METHODOLOGY & SOFTWARE** greenius + Matlab
5. **RESULTS**

1. MOTIVATION of Study



Field heat losses are between **7%** (Jordan, Ma'an) and **10%** (Guadix, Spain) of the collected solar energy
(Eurotrough-type, 70mm absorber, HTF: Oil)

Receiver design lifetime is **20-40 years**

However, lifetime may be reduced by

- Different maturity of products
- Limited experience in operation
- Increasing temperatures and new fluids
- Wind events with glass breakage

In case of failure, receiver heat loss may be increased by a **factor 5 to 10**

Objective of study: Energetic and economic impact of different receiver performance loss scenarios

2. REFERENCE Parabolic Trough Plant

Technology

Modern **150-MW_{el} parabolic trough plant** in **Ma'an**, Jordan (DNI 2820 kWh/m^2a)

7.5h-molten salt storage

360 loops of **high-quality collectors** (η_{opt}= 0.78) (Eurotrough-geometry)

51'840 receivers (totaling 207 km), either standard or with Xe-capsule (+1.3% solar field cost est.)

Turbine 150 MW, efficiency 38.5%

Dry cooling, no fossil firing

Economy

Investment costs 4 M€/MW_{el}

Annual O&M + Ins.: 2.4%*I

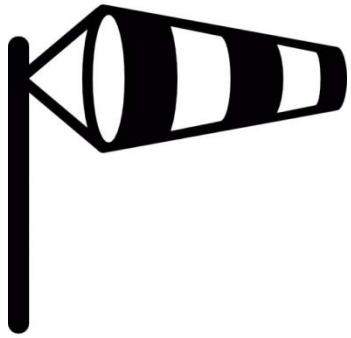
Discount rate 6%, 25% equity, 75% debt (5% interest rate), 25 yrs operation

→ **LEC 11.3 €cent/kWh_{el}**

3. SCENARIOS for Receiver Performance Loss

Event

- "**Wind A/B**" Wind event destroying glass envelopes
- "**H_2**" Hydrogen accumulation
- "**AR**" Anti-reflection coating degradation

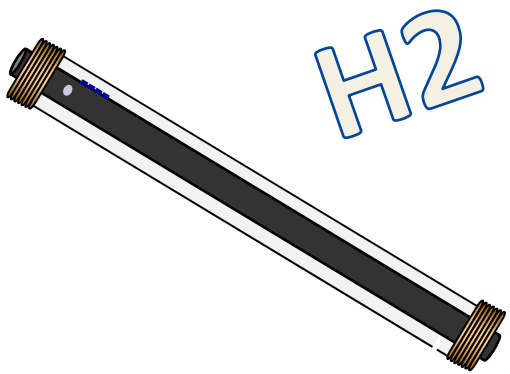


Affected Field

- **50%** (H_2) or **100%** (AR) of field
- Limits of field (**5.6%**, Wind)

Variation of *point in time* when damage occurs

- **sudden** event year ***t*=5**, **10**, or **15**
- **gradual** damage (AR) **1..5**, **1..10**, **1..15**

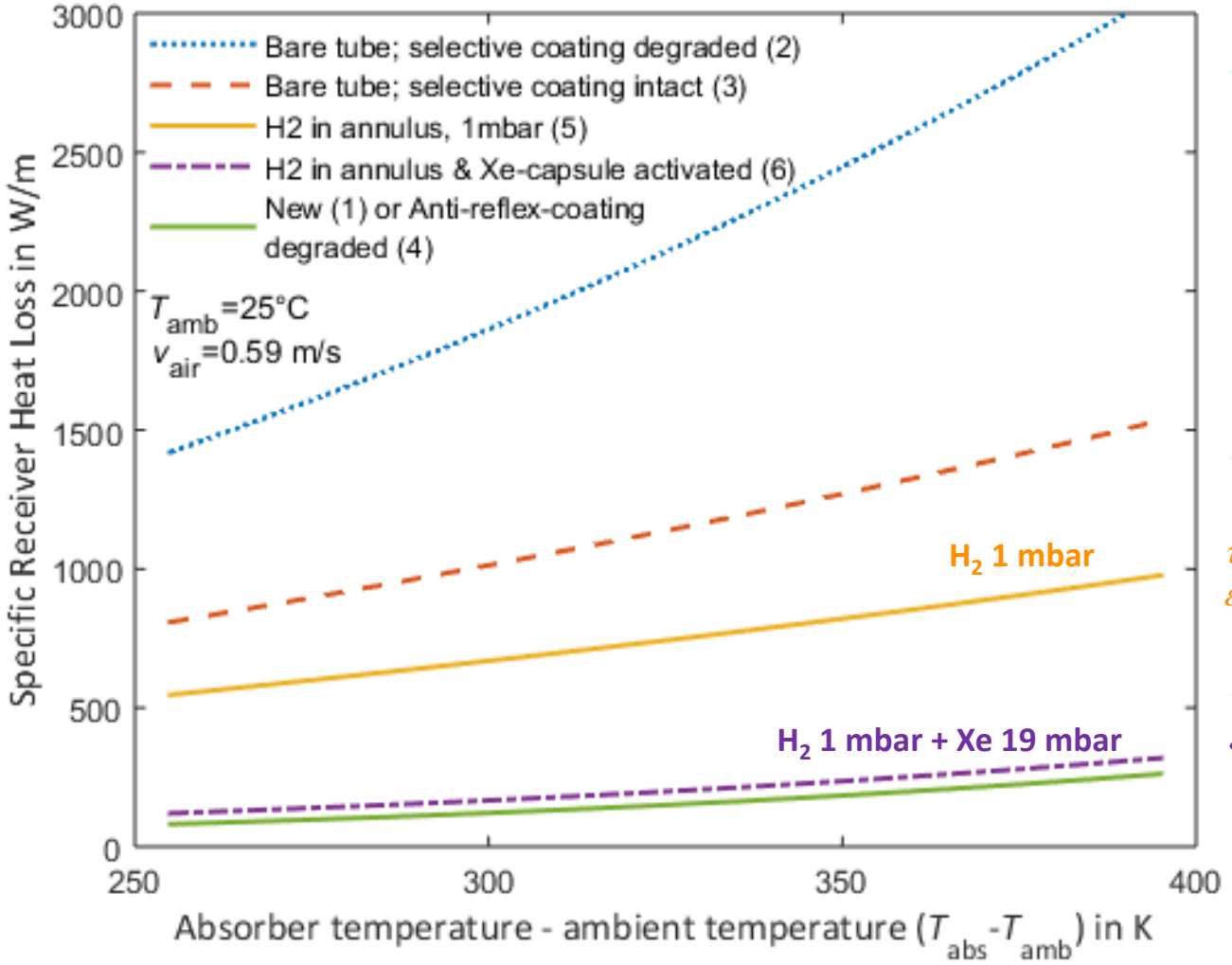


Different counter measures (full performance in year t+2)

- "**Leave**" damaged receivers (do nothing)
- "**Replace**" damaged receivers
- Activate "**Xenon**" capsule (H_2 accumulation)
- "**Fix**" receivers (H_2 accumulation)

3. SCENARIOS for Receiver Performance Loss

Heat Loss of Regarded Receivers



τ=**100%**; α_{sol} = **55%**, ε=**65%, free convection**

τ=**100%**; α_{sol} = 96%, ε=8-9%, **free convection**

τ=97%; α_{sol} = 96%, ε=8-9%, h_{ann}=**12.4 W/m²K**

τ=97%; α_{sol} = 96%, ε=8-9%, h_{ann}=**0.8 W/m²K**

τ=97/92%; α_{sol} = 96%, ε=8-9%, h_{ann}=0.0 W/m²K

4. METHODOLOGY

greenius
THE GREEN ENERGY SYSTEM ANALYSIS TOOL

Main_StartGreeniusCmd.m

PATHS	*Working Path* D:\DLR\90_Veröffentlichungen\2015_greenius_UserConference_Pareso *Project Name* 'H2A_t10_R_trial' *PARESO-Toolbox-Path* D:\SVN\SFMatlabTools\IR_TransThermo\GreenParesoToolbox_v1.0 *Greenius Bib Path* .... Block_06_Greenius_Files\data
SOLAR FIELD DEF.	*mat* Matrix with Receiver_Type // agefaktor_epsilon // agefaktor_tau*alpha // colfrom // colto // yr_from // yr_to *fak* Value containing eta_opt_col, bereinigt durch Receivereigenschaften
RESULTS TO MATLAB	*vec0, vec1, vec2* Definition which rows will be read from *csv into Matlab result structrure

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4. METHODOLOGY

greenius
THE GREEN ENERGY SYSTEM ANALYSIS TOOL

Main_StartGreeniusCmd.m

PATHS

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Project Name 'H2A_t10_R_trial'
PARESO-Toolbox-Path D:\SVN\SFMatlabTools\IR_TransThermo\GreenParesoToolbox_v1.0
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RECEIVER PROPERTY DATABASE

Heat loss coefficients
b0, b1, b2, b3, b4

Transmittance, Solar Absorptance
tau, alpha

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4. METHODOLOGY

greenius
THE GREEN ENERGY SYSTEM ANALYSIS TOOL

Main_StartGreeniusCmd.m

PATHS

Working Path D:\DLR\90_Veröffentlichungen\2015_greenius_UserConference_Pareso
Project Name 'H2A_t10_R_trial'
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Transmittance, Solar Absorptance
tau, alpha

PREPARE greenius FILES

Greenius Project File ***.gpj**
Collector File ***.gpa**

b0 matrix
b1 matrix
b2 matrxi
b3 matrix
b4 matrix

Thermal Prop. = **f**(Loc, Time)

eta_opt_col matrix

Optical Prop. = **f**(Loc, Time)

AddOMCosts ***.gpa**

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4. METHODOLOGY

greenius
THE GREEN ENERGY SYSTEM ANALYSIS TOOL

Main_StartGreeniusCmd.m

PATHS
Working Path D:\DLR\90_Veröffentlichungen\2015_greenius_UserConference_Pareso
Project Name 'H2A_t10_R_trial'
PARESO-Toolbox-Path D:\SVN\SFMatlabTools\IR_TransThermo\GreenParesoToolbox_v1.0
Greenius Bib Path .... Block_06_Greenius_Files\data

SOLAR FIELD DEF.
mat Matrix with Receiver_Type // agefaktor_epsilon // agefaktor_tau*alpha // colfrom // colto // yr_from // yr_to
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PREPARE greenius FILES
Greenius Project File ***.gpj**
Collector File ***.gpa**
b0 matrix
b1 matrix
b2 matrxi
b3 matrix
b4 matrix
Thermal Prop. = **f**(Loc, Time)
eta_opt_col matrix
Optical Prop. = **f**(Loc, Time)
AddOMCosts ***.gpa**

START GREENIUS `dos(['Greenius ',[prj_path,proj_Name,'.gpj'],' ',prj_path ]);`

RESULTS greenius *,csv-Files
ReadGreeniusResultsCSVFunc.m
Matlab Workspace *res* result structure
Plot

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4. METHODOLOGY

Matlab workspace res.TEC und res.ECO with results

```
Command Window
>> res.TEC

ans =

          TOT_Annual_thermal_field_output: [1x1
        TOT_Solar_annual_net_electr_output: [1x1
      TOT_Solar_annual_gross_electr_output: [1x1
        TOT_Total_annual_net_electr_output: [1x1
      TOT_Total_annual_gross_electr_output: [1x1
         TOT_Specific_thermal_field_output: [1x1
            TOT_Specific_electrical_output: [1x1
          TOT_Mean_annual_field_efficiency: [1x1
                TOT_Mean_system_efficiency: [1x1
                           TOT_Solar_share: 100
                                      Year: [25x
              Annual_thermal_field_output: [1x2
            Solar_annual_net_electr_output: [1x2
          Solar_annual_gross_electr_output: [1x2
            Total_annual_net_electr_output: [1x2
          Total_annual_gross_electr_output: [1x2
             Specific_thermal_field_output: [1x2
                Specific_electrical_output: [1x2
              Mean_annual_field_efficiency: [1x2
                    Mean_system_efficiency: [1x2
                               Solar_share: [1x2
```

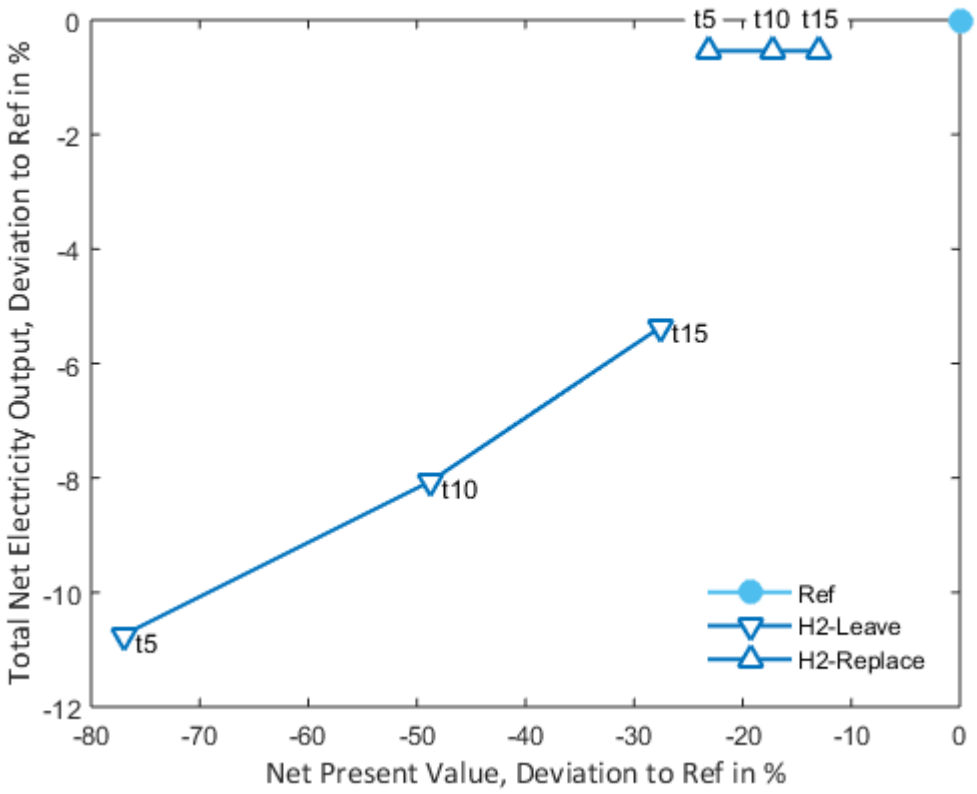
```
Command Window
>> res.ECO

ans =

                        Electricity_Tariff: [1x1 double]
                           DebtEquityRatio: 75
                      Average_Interest_Rate: 5
      Internal_Rate_of_Return_IRR_on_Equity: [1x1 double]
                          Net_Present_Value: [1x1 double]
                             Payback_Period: [1x1 double]
                  Discounted_Payback_Period: [1x1 double]
           Levelized_Electricity_Costs_LEC: [1x1 double]
            Discounted_Investment_Costs_IC: [1x1 double]
               Discounted_Running_Costs_OC: [1x1 double]
                        TOT_Total_Revenues: [1x1 double]
                  TOT_Total_Running_Costs: [1x1 double]
                       TOT_Equity_Funding: [1x1 double]
                    TOT_Post_Finance_CF: [1x1 double]
                         TOT_Post_Tax_CF: [1x1 double]
                      TOT_Discounted_CF: [1x1 double]
                    TOT_Disc_Equity_Inj: [1x1 double]
                    TOT_EquityDividends: [1x1 double]
                                   Year: [27x1 double]
                        Total_Revenues: [1x27 double]
                    Total_Running_Costs: [1x27 double]
                         Equity_Funding: [1x27 double]
                      Post_Finance_CF: [1x27 double]
                          Post_Tax_CF: [1x27 double]
                       Discounted_CF: [1x27 double]
                     Disc_Equity_Inj: [1x27 double]
                     EquityDividends: [1x27 double]
```

5. RESULTS

Net Present Value



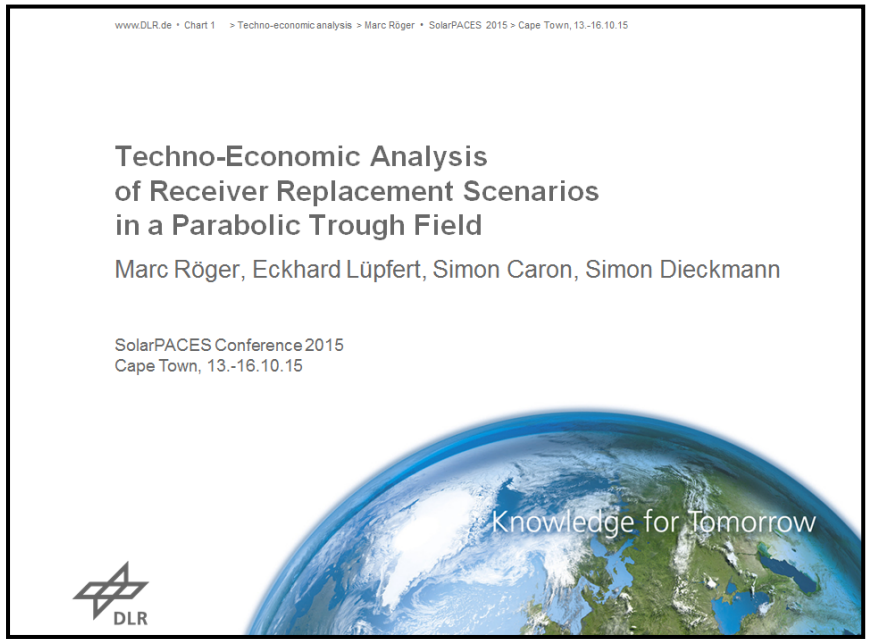
Maximum electricity production and maximum economic success
→ “Ref”, right top corner

H_2 accumulation may reduce **net present value up to 77%** and total generated **electricity up to 11%** over plant lifetime

Replacement (or fixing) is both **economically and energeti-cally viable**

5. RESULTS

More results will be presented at the SolarPACES conference 2015 13.-16.10.15, Cape Town



Conclusion

- Successful adaptation of **greenius** for varying heat losses over loop and operating time
  - Similar implementation for public version is planned
    → *see presentation on current development*
- Console start for **greenius** calculations without GUI
- Matlab can be used to…
  - Set up project files
  - Start simulations
  - Analyse results

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

THANK YOU

for your attention.

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- ***PARESO**: Contract no. 0325412*
- ***FreeGreenius**: Contract no. 0325427*

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