enerMENA

Towards a Sustainable Implementation of Solar Thermal Power Plants Technology in the MENA

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Optimized integration of CSP plants into Jordan's power plant portfolio

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Content

1. Situation of Jordan
2. CSP – potential and characteristics
3. Methodology/ tool for efficient integration of renewable energy technologies
4. Application to Jordan
5. Strategy for integration of renewable energy technologies in Jordan
6. Conclusion and future work

Electricity Sector of Jordan

Actual situation

- **2010:**
- Installed Capacity: 3069 MW (+ 15,1% compared to 2009)
- Peak Load: 2650 MW (+ 15.2%)
- Generated Electricity: 14683 GWh (+ 3,3%)

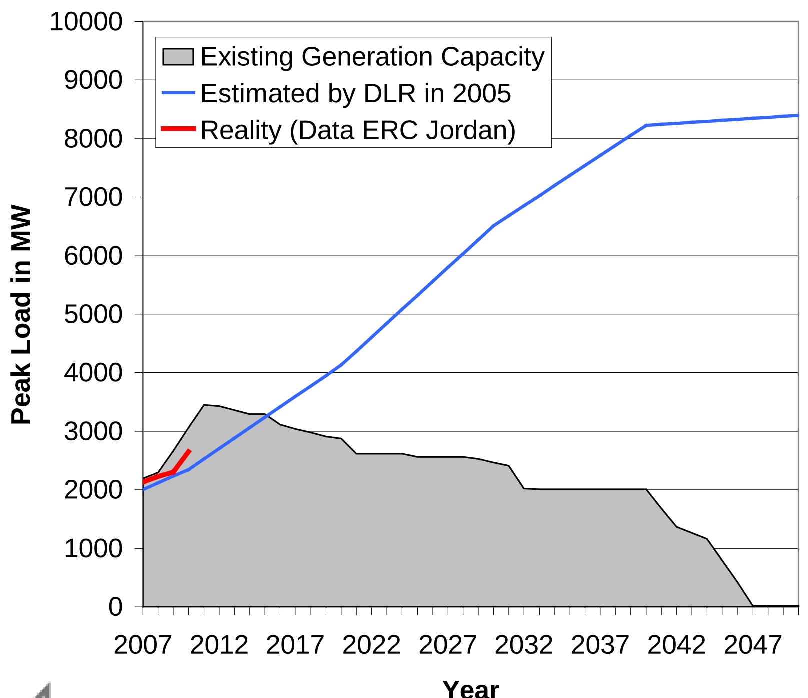
- Electricity generation heavily dominated by imported fossil fuels
- ≈ 80% by natural gas from Egypt

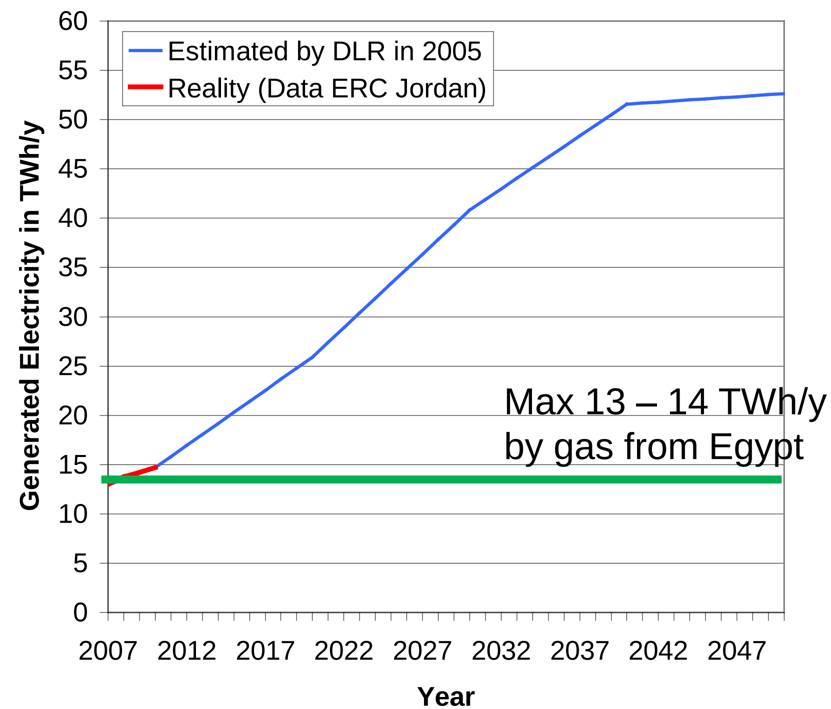
- **2011:**
- Gas supply from Egypt interrupted several times due to terroristic attacks
- Thereby increased use of expensive HFO & LFO for power generation
- Price for natural gas from Egypt increased almost by a factor of 3
- Annual natural gas supply restricted to about 3 billion m^3/y

Electricity Sector of Jordan

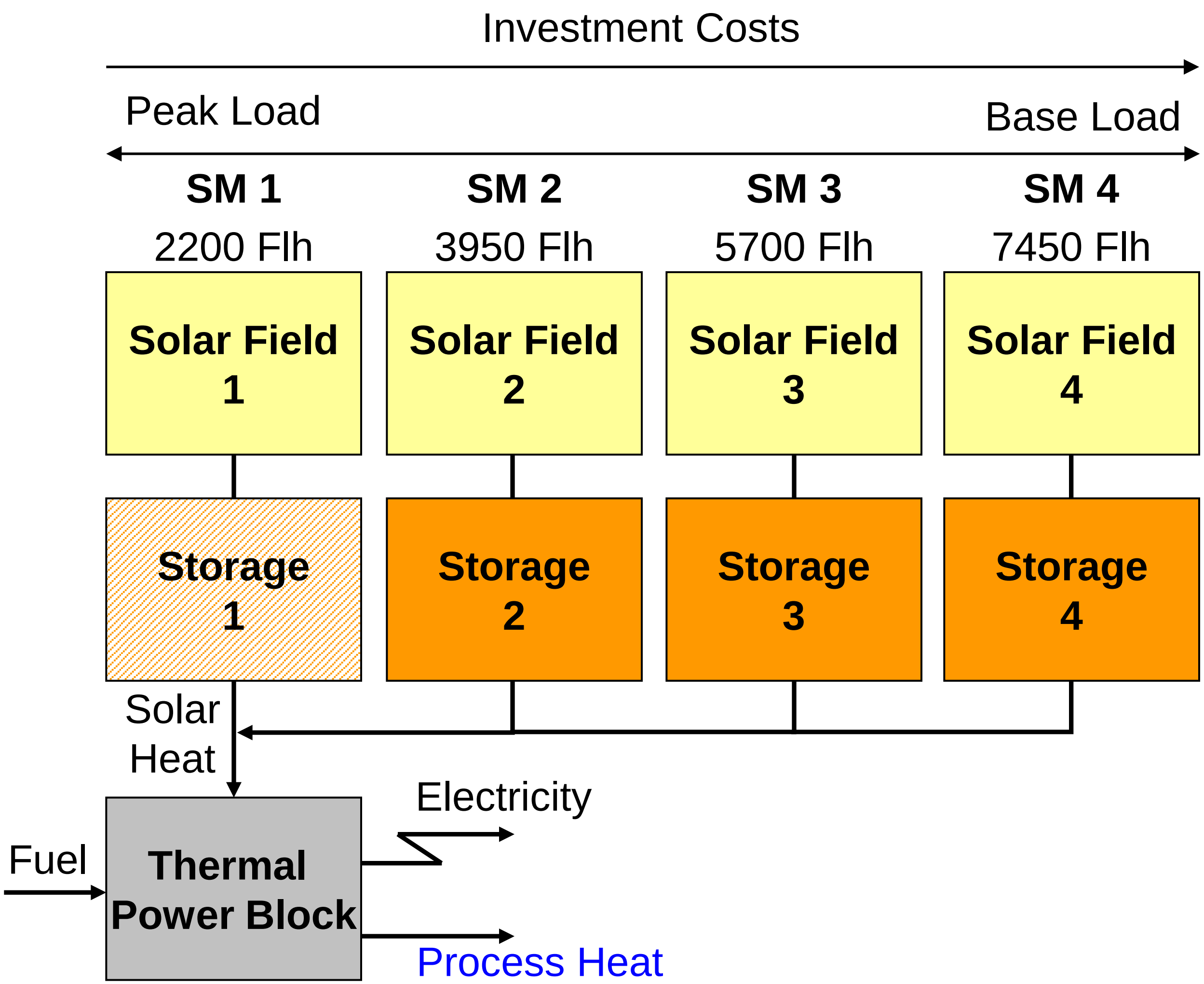
Future development

- Strong increase of peak load and annual electricity demand
- Large amount of new firm and flexible power generation capacity required
- Experienced increase of fossil fuel prices is likely to continue





Principle of Concentrating Solar Power Plants

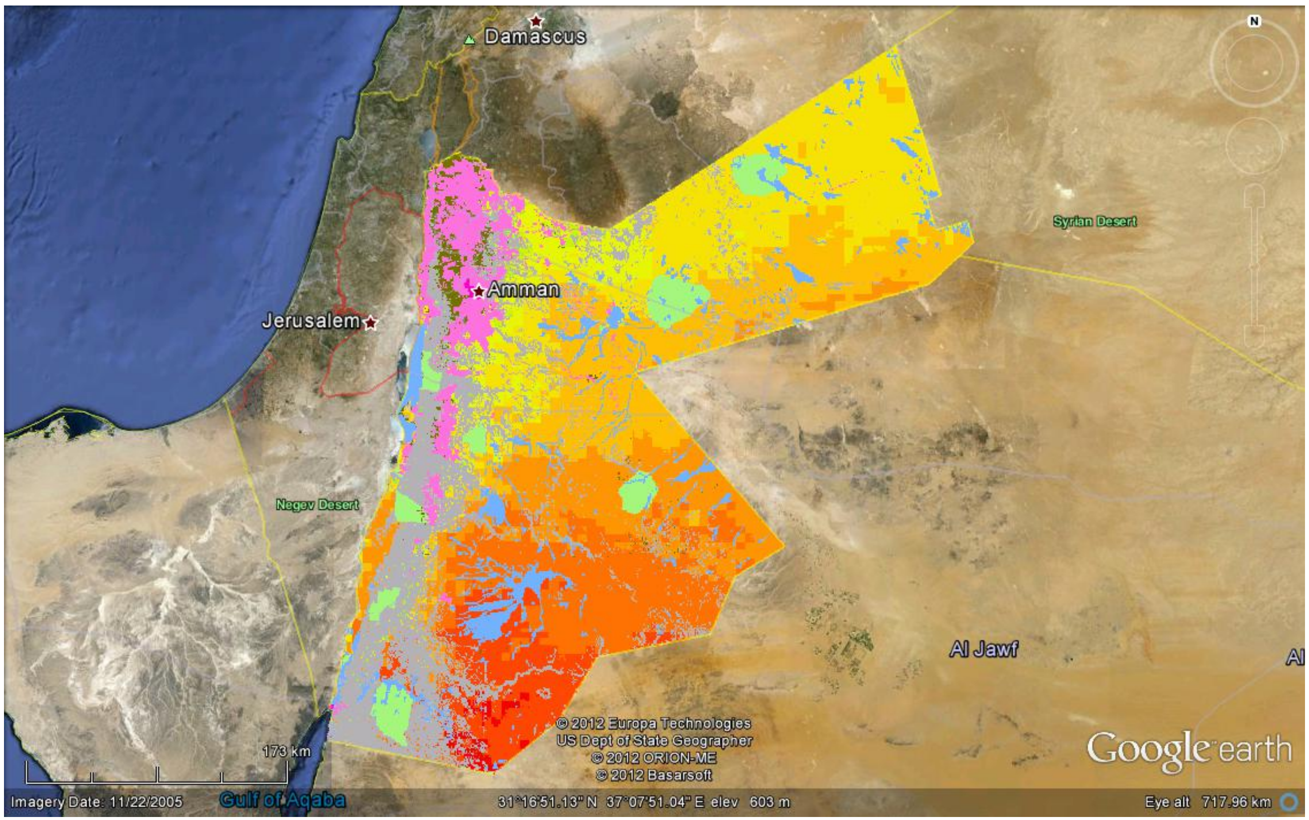


Qualities of CSP Plants:

- Operating as peak, medium or base load power plant
- Firm & flexible capacity
- Power on demand
- Spinning reserve
- Combined generation of process heat for industry, cooling, desalination, etc.

Potential of Concentrating Solar Power in Jordan

- Demand 2050: 53 TWh/y
- Potential CSP: 5884 TWh/y



DNI Classes [kWh/m²/y]

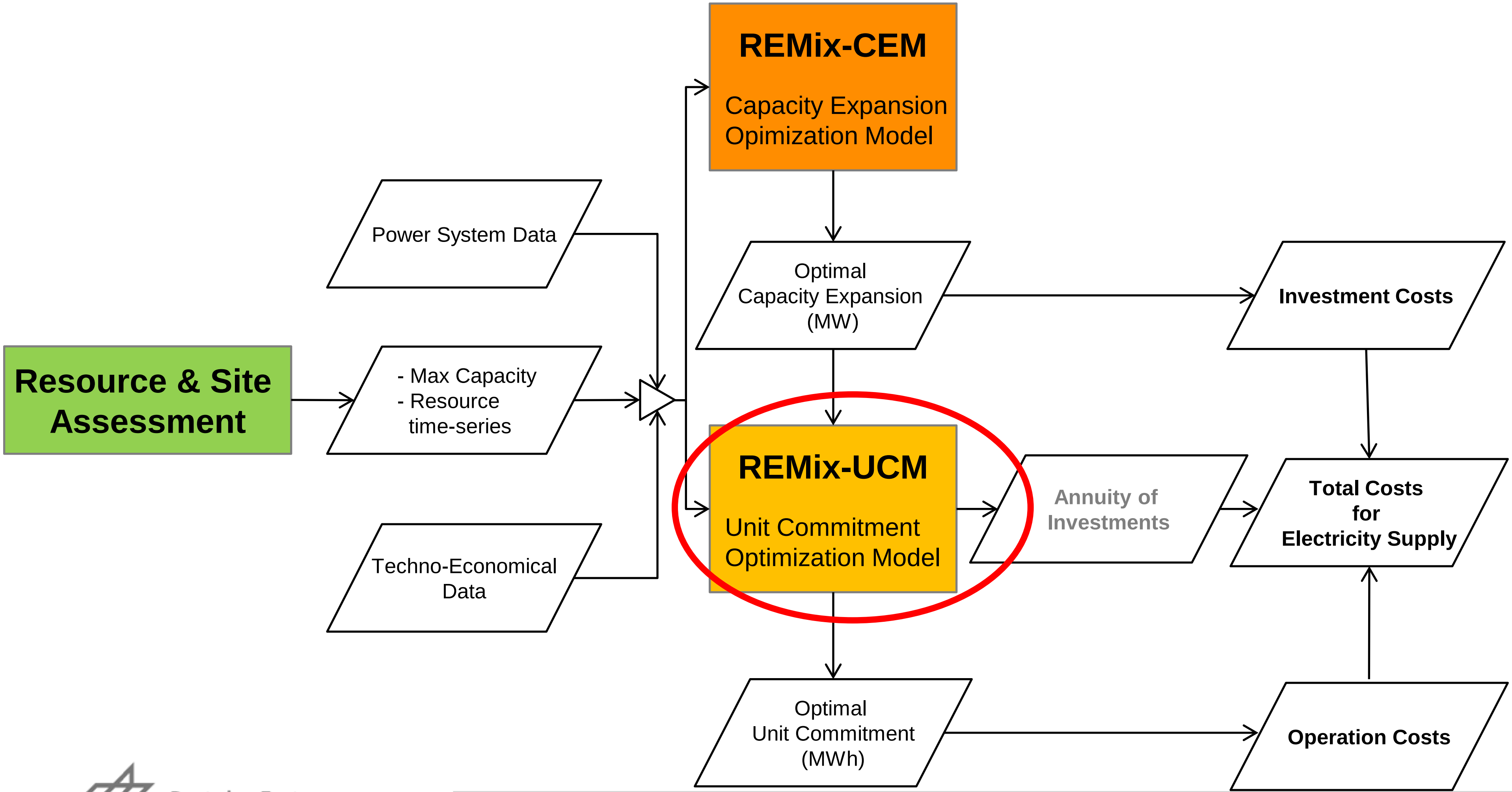
- < 1900
- 1,900
- 2,000
- 2,100
- 2,200
- 2,300
- 2,400
- 2,500
- 2,600
- 2,700

Exclusion Criteria

- Urban areas
- Population density
- Hydrography
- Land cover
- Protected areas
- Topography

General Methodology

Optimized Integration of CSP and other RE technologies in MENA countries



Resource & Site Assessment

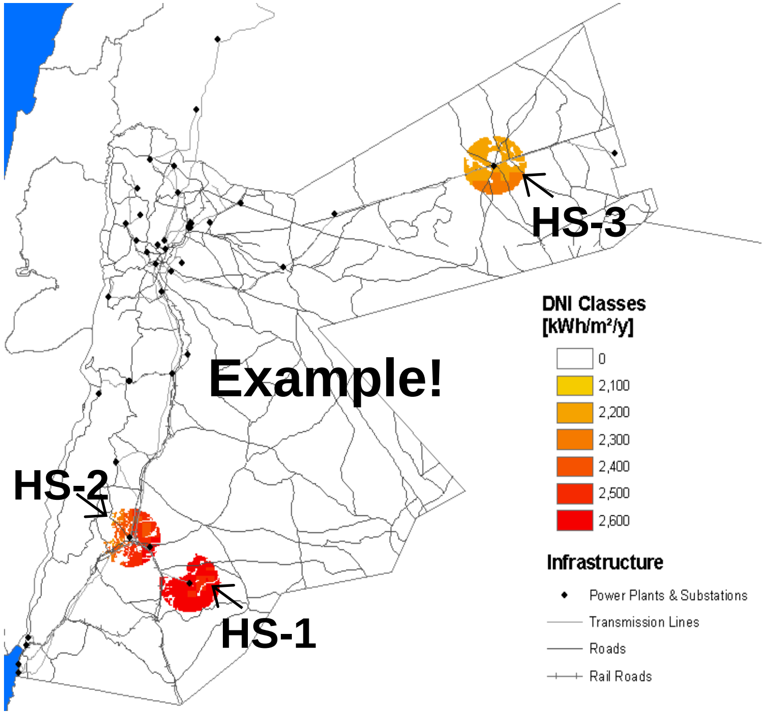
Identification of hot spots for each technology

Identification of Hot Spots:

- Due to technology specific land exclusion and site ranking processes
  (e.g. valuing resource availability and distance from infrastructure)

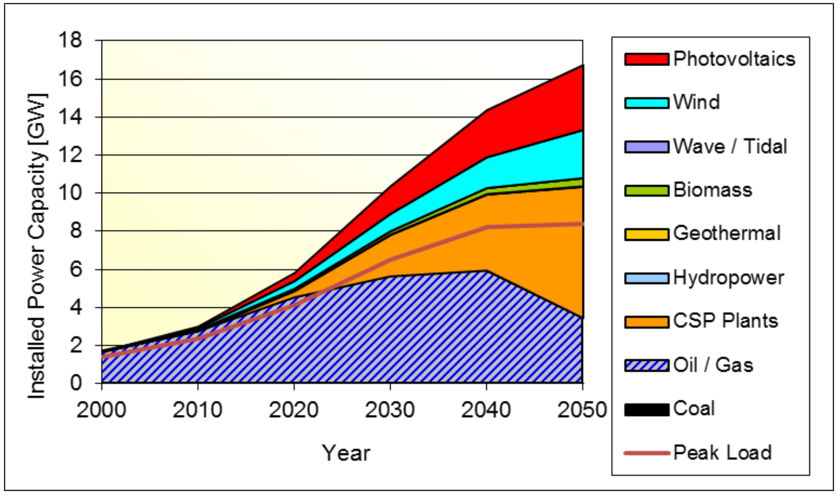
Information for each Hot Spot:

- Available area
- Maximum installable capacity
- Representative hourly resource profile
  (hourly values for DNI, GHI, wind speed)



REMix-CEM

Capacity Expansion Optimization Model



Main Characteristics:

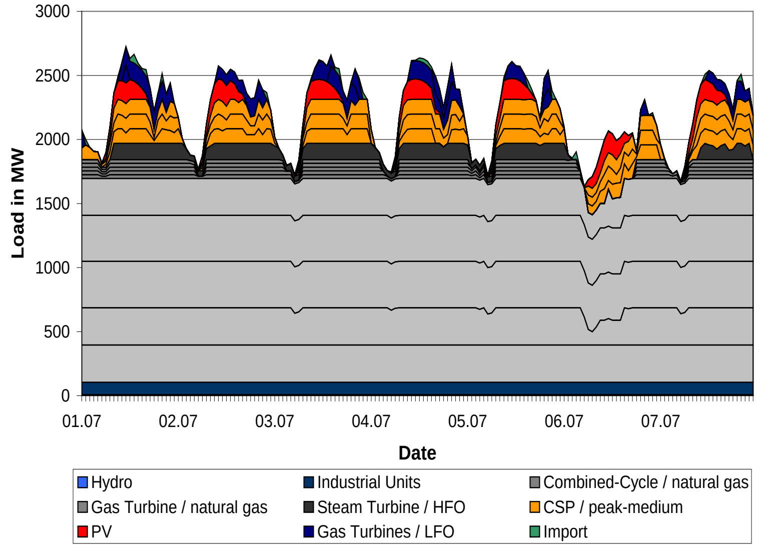
- Time-frame: 25 – 40 years
- Methodology: Load Duration Curve analysis (several LDC per year)

- Advantage: optimization of entire time-frame possible
- Disadvantage: - loss of short-term chronology
  - no consideration of inter-temporal constraints

- Output: - optimized build schedule for new power plants
  - investment costs
  - rough estimation of operation costs

REMix-UCM

Unit Commitment Optimization Model



Main Characteristics:

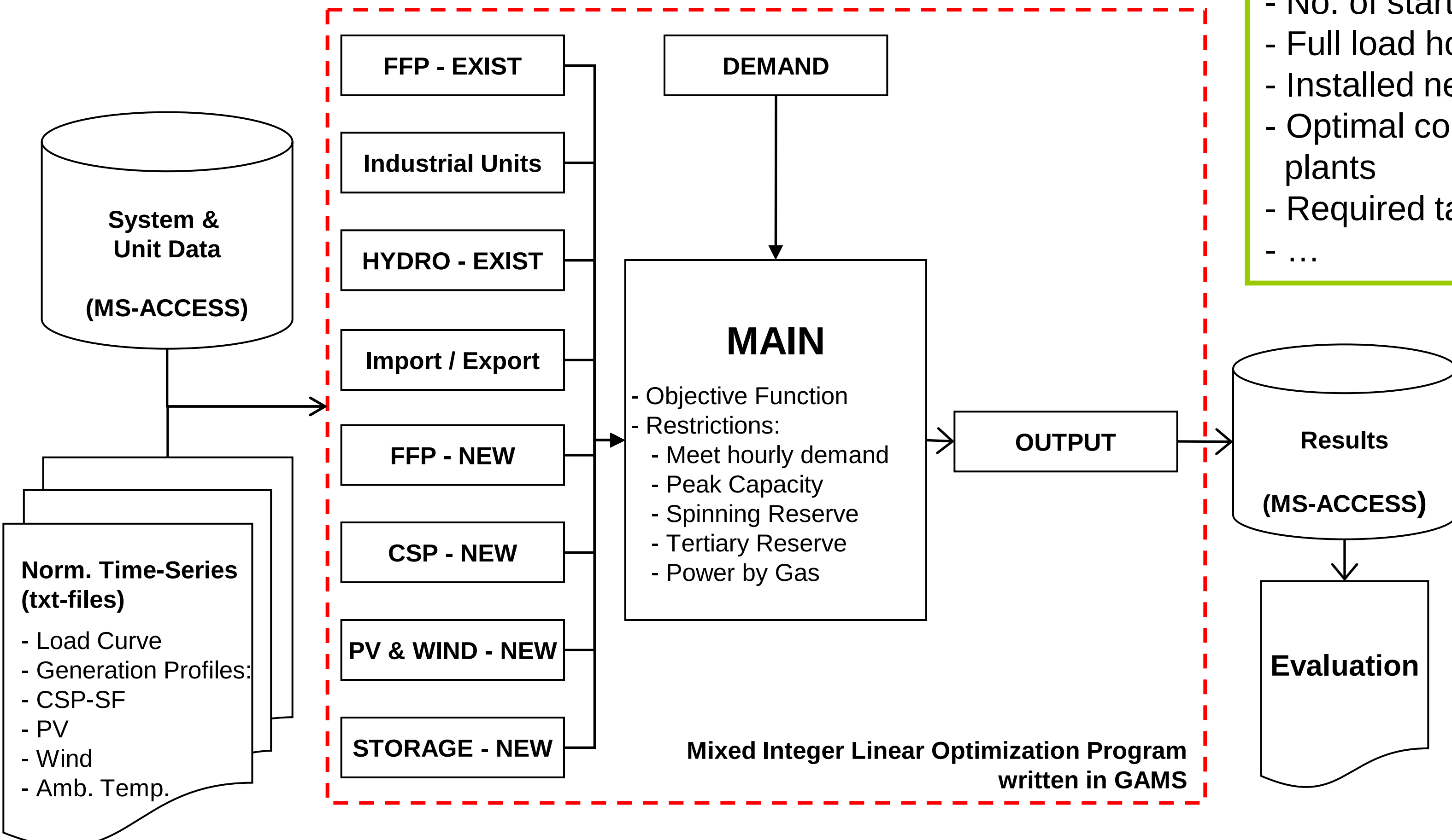
- Time-frame: 1 year, 1h time-steps
- Methodology: Annual load curve analysis
- Advantage: Taking into account inter-temporal constrains
- Disadvantage: computationally intensive, investigation of only 1 year
- Output:
  - Optimized unit commitment schedule
  - Detailed unit specific operation costs
- Application:
  - complementary to REMix-CEM
  - identification of niche markets for CSP and other renewable energy technologies
  - within stepwise capacity expansion planning

REMix-UCM: General Structure

Minimizing total annual system costs

Examples of Output:

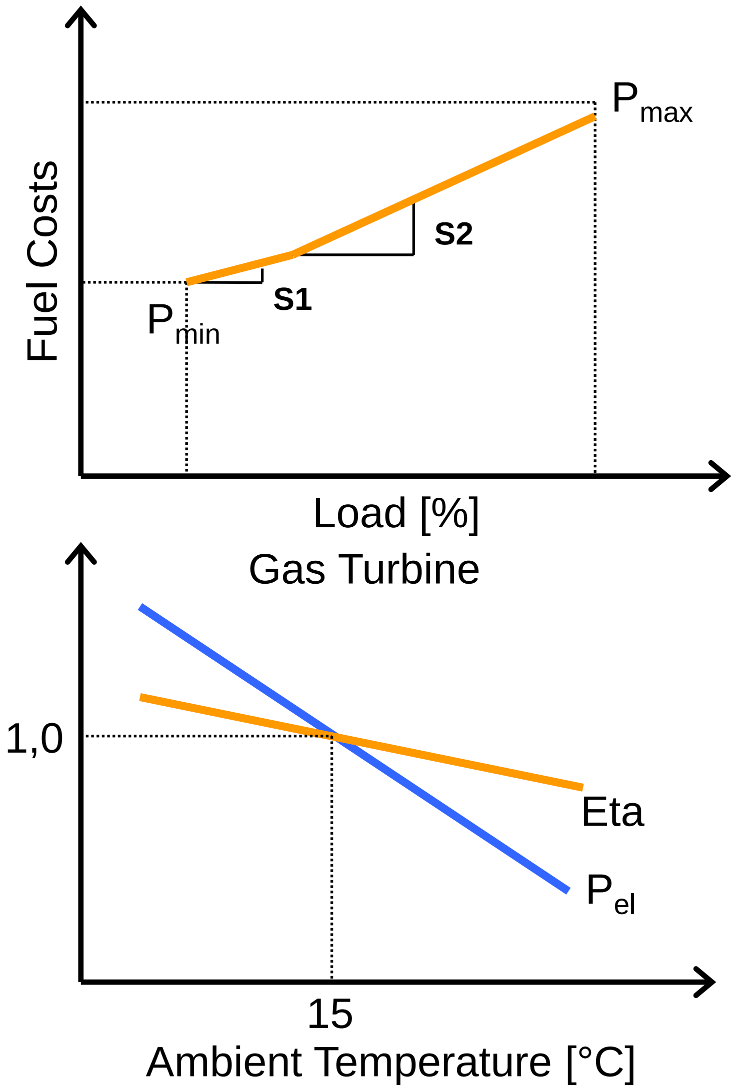
- Total system costs
- Ø electricity generation costs
- Unit commitment
- Unit specific marginal costs
- No. of start-ups of each unit
- Full load hours of each unit
- Installed new capacity
- Optimal configuration of CSP plants
- Required tariff for RE-projects
- …



REMix-UCM

Detailed modelling of power plants

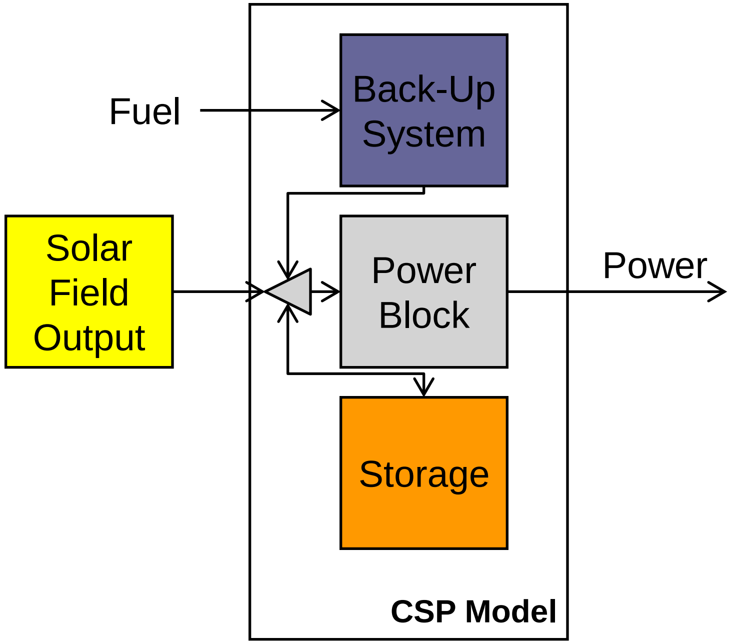
- Unit specific modelling
- Min./ max. load
- Parasitics
- Part load efficiency
- Min. on- & offline time
- Max. ramp rates
- Start-up & shut-down costs
- Variable & fix O&M costs
- Fuel costs
- Temperature influence
- (Investment costs)
- …

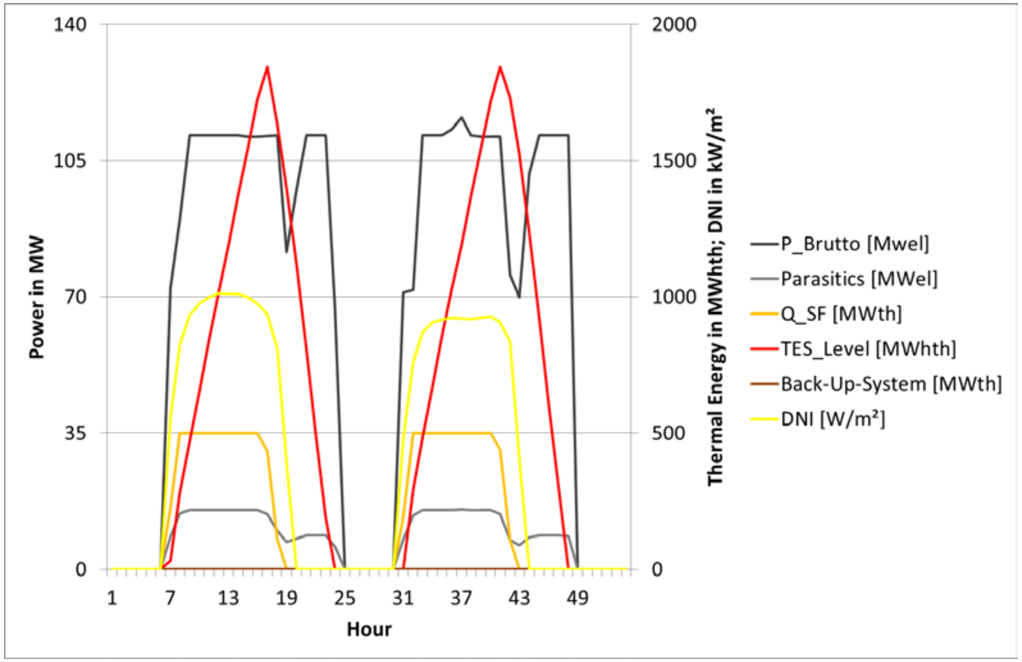


REMix-UCM

Detailed modelling of CSP power generation

- Size of solar field (SM) and thermal energy storage capacity can be optimized
- Share and size of co-fire system can be determined





Application of REMix-UCM to Jordan

Case study: Investigation of niche markets

- Question: CSP and PV already competitive today?
- Methodology: Comparing **marginal costs** of existing units with **full costs** of CSP and PV
- Investigation: Effects on total annual system costs when introducing max. **2x100 MW CSP** plants and max**. 200 MW PV** into the existing power plant park
- Requisite: Detailed hourly modelling of existing power plant park with all relevant technical and economical restrictions

Case Study: Niche Markets

General Input Data

Power System Data	Year 2012	
Total Demand	17,391	GWh
Peak Load	3,091	MW
Minimum Load	1,172	MW
Net Transfer Capacity	500	MW
Peak Reserve Factor	10%	
Required Peak Capacity	3,400	MW
Installed Capacity	3,535	MW
Natural Gas Availability	2.98	billion m³/y
GAS	0.016	€/kWhth
HFO	0.043	€/kWhth
LFO	0.054	€/kWhth

Fuel Prices			
Date	02.07.2012		
Dollar-Euro		1.31	EUR/1USD
Crude Oil		111.70	USD/bbl
	World Market	**Jordan**	
Natural Gas	13.5	6.1	USD/MMBtu
Bunker Oil (HFO)	745	596	USD/mt
Diesel (LFO)	1,047	837	USD/mt

Site Data		
DNI	2487	kWh/m²/y
GHI	2288	kWh/m²/y

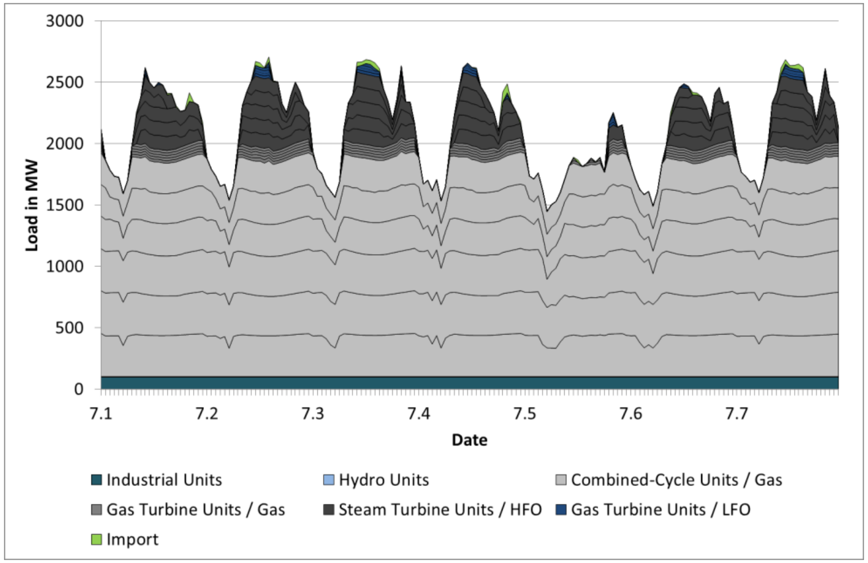
Data - Existing Units	No. of Units	Capacity
	#	MW
Combined-Cycle Power Plants	6	2,020
Gas Turbine Power Plants	15	389
Steam Turbine Power Plants	12	1,018
Industrial Companies	5	102
Hydro Power	1	6
Wind	-	-
Total	**39**	**3,535**

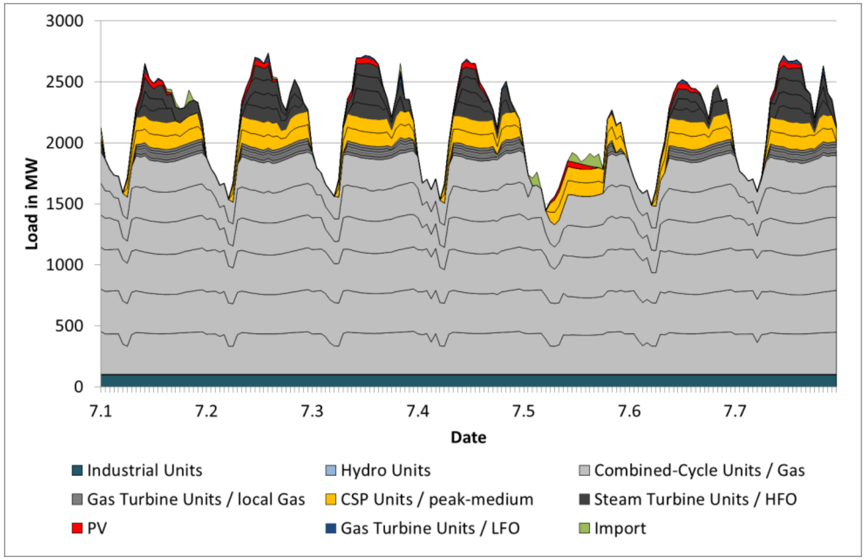
		CSP	PV
No. Of Units		2	1
Netto Capacity of Unit	MW	100	max 200
Solar Multiple		1.5	x
Storage Capacity	Flh	6	x
Specific Investment Costs	€/KW	5175	2200
Operation Costs	€/kWh	0.025	0.015
Amortization Time	y	30	20
WAAC		7%	7%

Case Study: Results

Main Results		w/o RE	w RE
Average Generation Costs	€/kWh	0.056	0.056
Average Base Load Costs	€/kWh	0.036	
Average Mid-Merit Costs	€/kWh	0.135	
Average Peak Load Costs	€/kWh	0.190	
LEC CSP	€/kWh	0	0.148
LEC PV	€/kWh	0	0.121
Full Load Hours CSP	h	0	3575
Full Load Hours PV	h	0	2060
Installed Conventional Capacity	MW	3535	3535
Installed CSP Capacity (netto)	MW	0	200
Installed PV Capacity	MW	0	60
Generation by Gas	%	87.5	85.9
Generation by HFO	%	11.1	8.1
Generation by LFO	%	0.6	0.3
Generation by Hydro	%	0.3	0.3
Generation by CSP	%	0.0	4.4
Generation by PV	%	0.0	0.7
Import	%	0.5	0.3

- CSP already competitive in peak / upper mid-merit load segment
- PV as “fuel saver” replacing expensive LFO

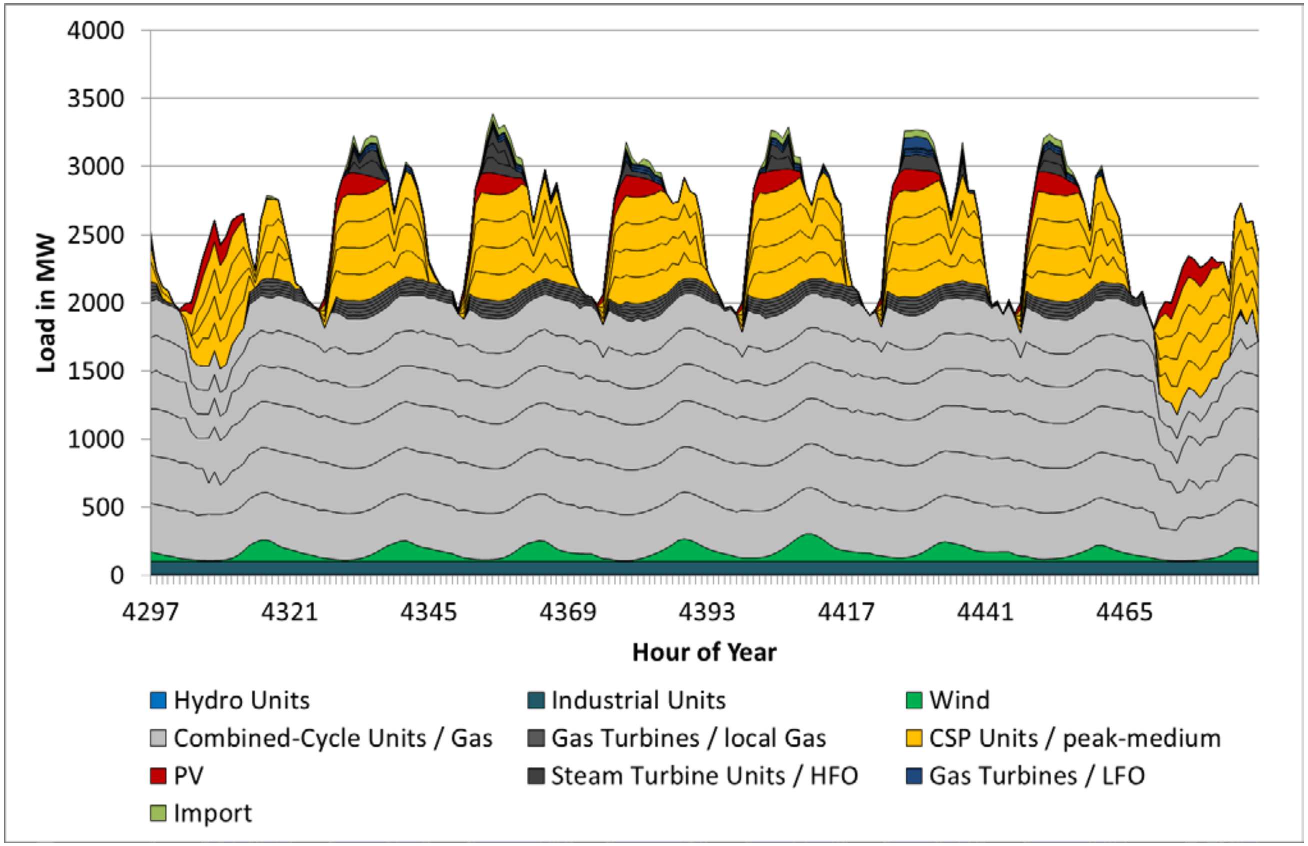




Strategy for Integration of RE Technologies in Jordan

Short-term…

- CSP as peak / upper mid-merit power plants providing strongly required firm and flexible power capacity
- CSP Configuration:
  - SM: 1 - 2
  - TES: 3 - 6 h
  - Flh: 2000 - 4000
- PV and Wind Power as "fuel saver"

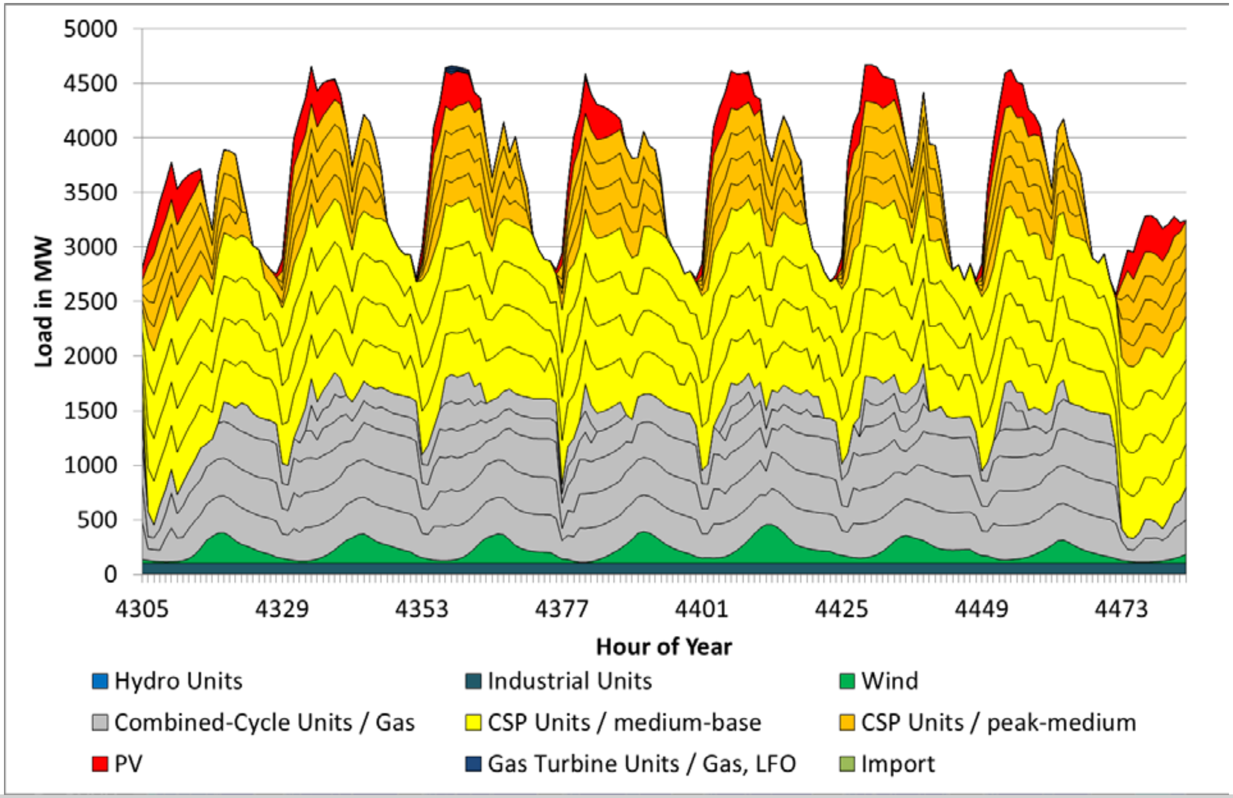


Strategy for Integration of RE Technologies in Jordan

Mid- & long-term…

- CSP becomes competitive with lower mid-merit and base load segment
- CSP as firm and flexible power capacity as backbone of electricity supply

- CSP Configuration:
  - SM: 2 - 3.5
  - TES: 6 - 18h
  - Flh: 4000 - 8000
- Share of PV and Wind Power further increased
- Fossil fuels used for peak load and in high efficient CC Units



Conclusions and Future Work

- **Conclusions:**
- CSP already competitive in peak and upper mid-merit load segment
- CSP only renewable energy technology which represents firm and flexible power capacity in MENA (no biomass, no pump-storage)
- Step-by-step integration will minimize subsidy requirements
- PV and Wind Power are important for saving expensive fossil fuels
- Large scale integration of renewable energy technologies will make Jordan more independent from future fossil price escalations

- **Future Work:**
- Up to now, developed tool mainly used for niche market identification
- Further development of tool
- Detailed calculation of capacity expansion
- Model must be validated with Jordan's electricity generation companies

Thank You!

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Back-Up Slides

REMix-UCM

Objective Function & major restrictions

- **Objective Function:** Minimization of Total Annual System Costs

$$C_n^{SYSTEM} =$$

$$\left. C_{FFP\_EXIST}^{OPEX} + C_{INDUSTRIAL}^{OPEX} + C_{HYDRO}^{OPEX} + \right\} \text{Marginal Costs}$$

$$\left. C_{FFP\_NEW}^{CAPEX} + C_{FFP\_NEW}^{OPEX} + C_{CSP}^{CAPEX} + C_{CSP}^{OPEX} + C_{PV}^{CAPEX} + C_{PV}^{OPEX} + C_{WIND}^{CAPEX} + C_{WIND}^{OPEX} \right\} \text{Full Costs}$$

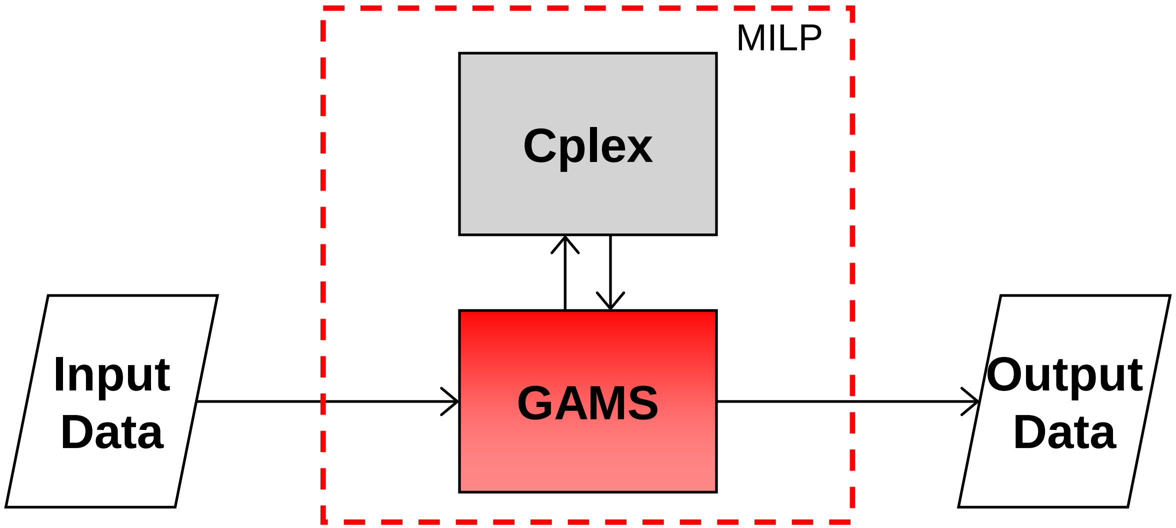
$$+ C_{IMPORT} - C_{EXPORT}$$

$$\Rightarrow \min .$$

- **Main Restrictions:**
  - Meet load in every hour of the year
  - Providing enough Peak reserve, spinning reserve, and tertiary reserve
  - Maximum annual natural gas availability

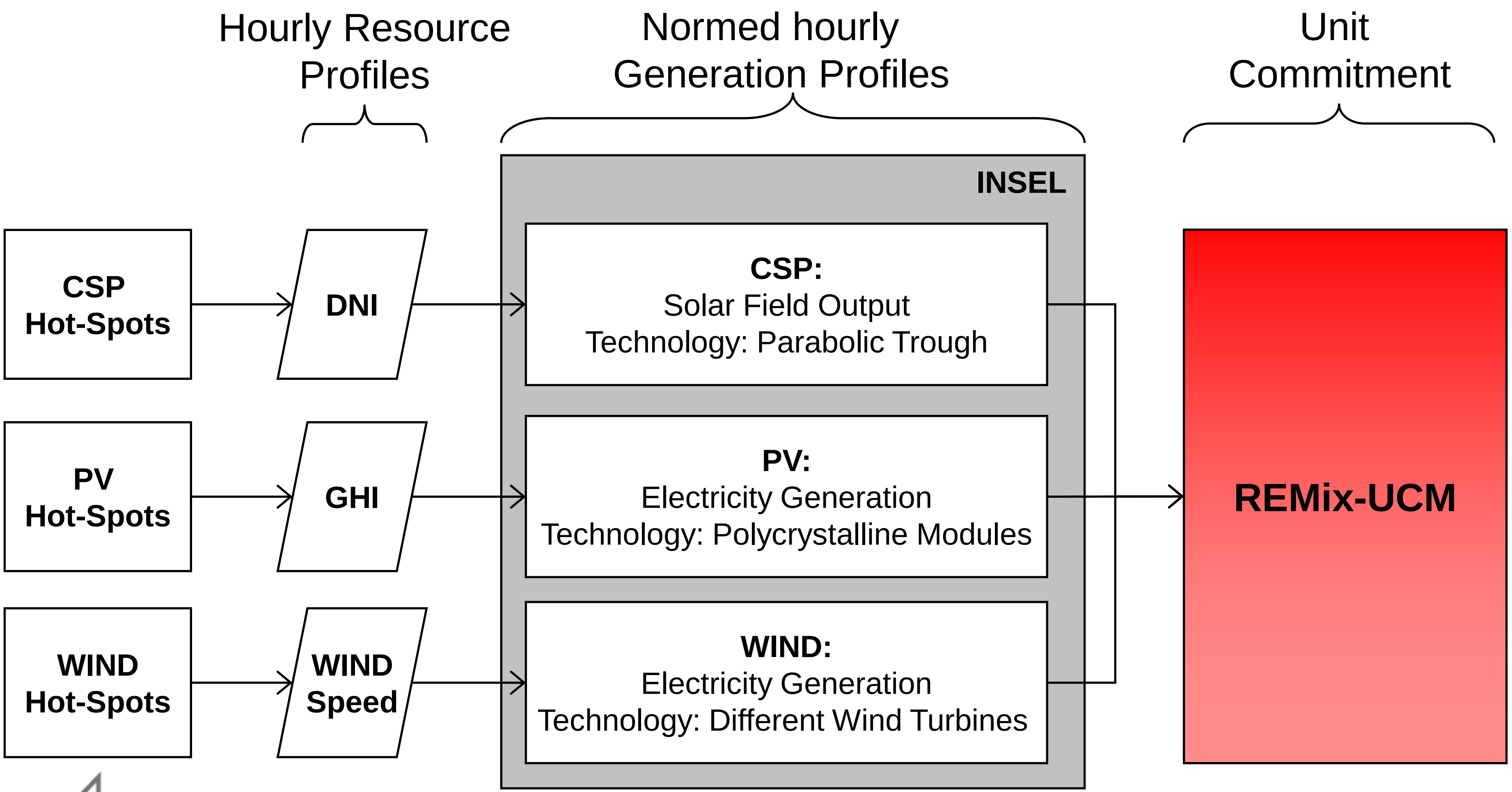
REMix-UCM
General Implementation

- Modelling Language: GAMS (General Algebraic Modelling System)
- Optimization Method: Mixed Integer Linear Programming (MILP)
- Solver: Cplex
- Principle: Minimization of the objective function (total system costs) as a function of parameters and several constraints on these variables



REMix – UCM

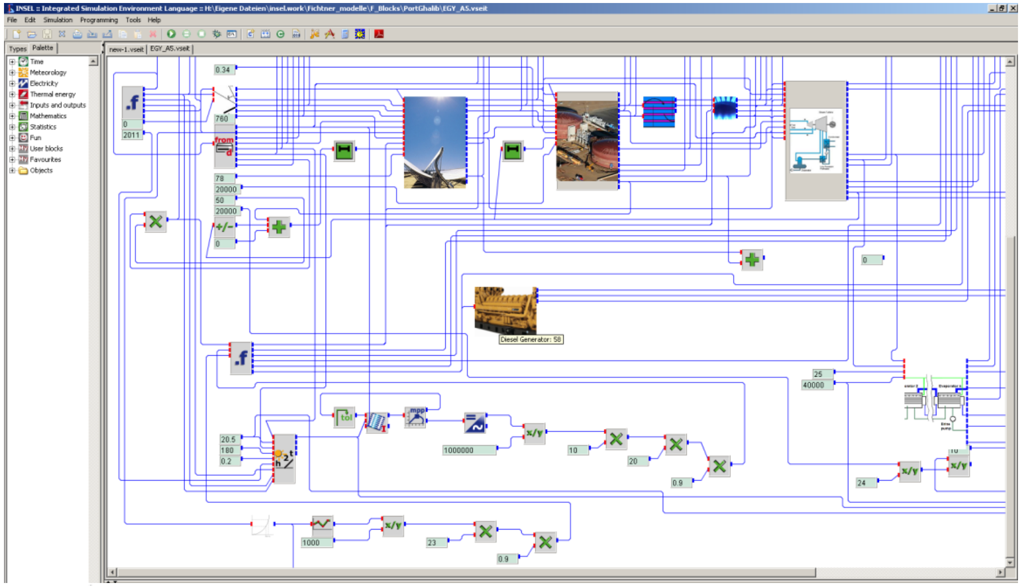
Process Chain Renewable Energy Technology Modelling



Normed Generation Profiles

INSEL: Integrated Simulation Environment Language

- Block-oriented tool for simulation of renewable energies
- Blocks for PV und Wind turbines are incorporated in libraries
- CSP- (solar field, thermal storage, power block) implemented by DLR and integrated in INSEL



Output:

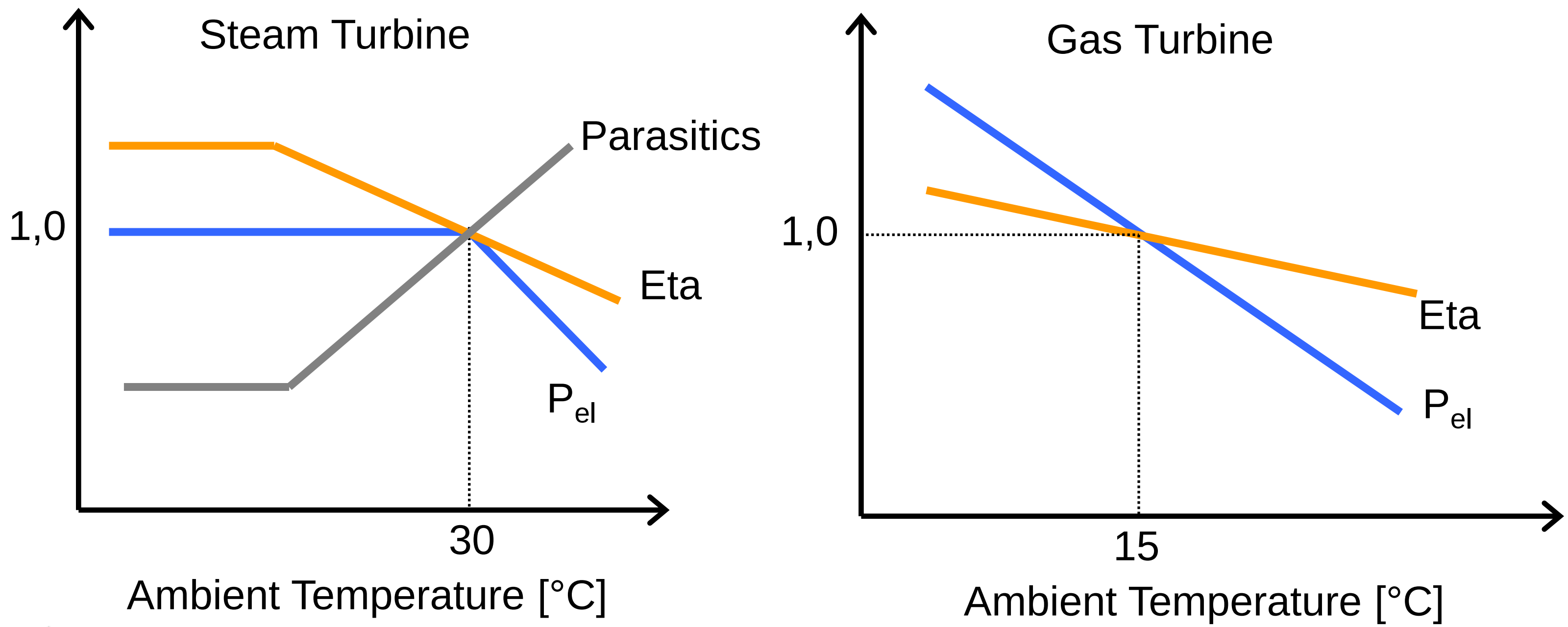
normed hourly output of:

- PV and Wind power electricity generation
- Thermal power output of Parabolic Trough solar field

REMix – UCM

Influence of Ambient Temperature

- Ambient Temperature has great impact on gas and steam turbine performance
- Hourly temperature profiles at each power plant site are considered



Example for unit specific input data

Technical & Economical Input Parameters	Unit 1	...	Unit 39	
SubNode	S1	...	...	
Unit Name	[redacted]	...	...	
Capacity - brutto (P_b)	373	...	...	MW
Capacity - netto (P_n)	362	...	...	MW
First Year of Operation	2011	...	...	
LastYear of Operation	2046	...	...	
Unit Type	CC	...	...	
Cooling Type	DRY	...	...	
Fuel	GAS	...	...	
AltFuel	LFO	...	...	
Max. Ramp Rate	6.0%	...	...	of P_b/min
Parasitics Power Block @ max Load	3.0%	...	...	of P_b
Efficiency @ max Load - brutto	52.5%	...	...	
Efficiency @ min Load - brutto	42.0%	...	...	
Start-Up Time - hot/warm/cold	1/3/5	...	...	h
Minimum Online/offline Time	4/2	...	...	h
Minimum Load Rate	33%	...	...	of P_b
Fuel Use for Start	3.5	...	...	MWh_{th}/MW_{el}
O&M Costs - variable	3.5	...	...	EUR/MWh
O&M Costs - fix	0.7%	...	...	% of Inv. Costs
Number of Labor	30	...	...	persons
Labor Costs	70000	...	...	EUR/y
Abrasion Costs	11.5	...	...	EUR/MW
...		...	...	